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ESTABLISHMENT OF A CUTTING FLUID CONTROL SYSTEM (PHASE III)

G.A. LIEBERMAN

SEPTEMBER 1982

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) Phase III results are presented for the program entitled "Establishment of a Cutting Fluid Control System." The major Phase III objectives were to develop an economic model that would be used to specify a cutting fluid control system, conduct a demonstration of selected generic type fluids at the Rock Island Arsenal (RIA) and to provide technology transfer. Key results of the Phase I and II programs are also included to provide continuity of the Phase III results.		

20. ABSTRACT (cont)

The study showed the majority of observed machining operations involved milling, turning, grinding and boring procedures on 4100 series steels. Through the use of an economic model, it was demonstrated that two generic type cutting fluids can satisfy 90% of all the machining operations at RIA. Also, three central cutting fluid recycling systems were recommended for use in three major production areas.

During the demonstration portion of the program, it was proven that laboratory tests can, indeed, be used to predict what will happen in a production environment. A 50% reduction in tooling costs was predicted through laboratory testing and verified by production tests at RIA.

Technology transfer was accomplished by: 1) a step-by-step procedure that RIA can use to evaluate future cutting fluids, 2) a specially designed procedure which RIA personnel can use to select cutting fluids within RIA, and 3) detailed quarterly and final reports.

The projected annual cost savings of this program amount to \$1,975,000.

FOREWORD

This report was prepared by Mr. G. A. Lieberman, Machining Technology, TRW, Inc., Cleveland, OH, in compliance with Contract No DAAA08-80-C-0033. Program management was provided by Mr. J. C. Lawrence, Section Manager, and Dr. C. F. Barth, Department Manager. Technical support was provided by J. M. Gorse, C. M. Imler, and R. A. Whittington. The TRW Internal Report No ER-8156F has been assigned for this project.

This work was under the direction of the Engineering Directorate, Rock Island Arsenal, Rock Island, IL, with Mr. R. E. Johnson as project engineer.

This project was authorized as part of the Manufacturing Methods and Technology Program and was administered by the US Army Industrial Base Engineering Activity.

TABLE OF CONTENTS

	<u>Page</u>
1.0 INTRODUCTION	1-1
2.0 BACKGROUND AND TECHNICAL APPROACH	2-1
2.1 Technical Approach	2-1
3.0 RESULTS AND DISCUSSION	3-1
3.1 RIA Cutting Fluid Demonstration	3-1
3.2 Cutting Fluid Evaluation Algorithm	3-9
3.3 Economic Model for Cutting Fluid Selection	3-17
3.4 Projected Cost Savings After Implementation of Recommended Generic Type Cutting Fluids	3-21
3.5 Cutting Fluid Compatibility Test Results	3-23
3.6 Cutting Fluid Selection Procedure	3-23
3.7 Cutting Fluid Recycling	3-33
4.0 CONCLUSIONS	4-1
4.1 RIA Manufacturing Processes and Materials	4-1
4.2 RIA Current Cutting Fluid System	4-2
4.3 Fluid Testing Conclusions	4-3
4.4 Demonstration Conclusions	4-5
4.5 Cutting Fluid Recycling Conclusions	4-5
5.0 RECOMMENDATIONS	5-1
5.1 Immediate Recommendations	5-1
5.2 Long Range Recommendations	5-2
6.0 REFERENCES	6-1
APPENDICES A through H	

LIST OF TABLES

<u>Table No.</u>	<u>Title</u>	<u>Page</u>
3.1-1	Milling Insert Tool Wear Measurements	3-3
3.1-2	Turning Insert Tool Wear Measurements	3-7
3.4-1	Projected Cutting Fluid Cost Savings	3-22
3.5-1	Results of the Cutting Fluid Compatibility Tests	3-24
3.6-1	RIA Cutting Fluid Application Matrix Based on TRW's Laboratory Performance Tests	3-28
5.2-1	Projected Yearly Cost Savings for the Recommended Central Cutting Fluid Recycling System and Generic Cutting Fluid. . .	5-5

LIST OF FIGURES

<u>Figure No.</u>	<u>Title</u>	<u>Page</u>
3.1-1	10x photographs of milling demonstration test inserts used with Master Chemical's Trimsol after machining four parts.	3-4
3.1-2	10x photographs of milling demonstration test inserts used with D.A. Stuart's Dascool 502 after machining four parts	3-5
3.2-1	Data Collection Questionnaire Used for Products Diluted in Water	3-10, 11
3.2-2	Data Collection Questionnaire Used for Neat Oils	3-12, 13
3.2-3	Turning Cutting Fluid Performance Data Analysis Sheet	3-15
3.2-4	Graph for Recording Turning Cutting Fluid Performance Test Results.	3-16
3.2-5	Milling Cutting Fluid Performance Data Analysis Sheet	3-18
3.2-6	Graph for Recording Milling Cutting Fluid Performance Test Results.	3-19
3.6-1	RIA Machining Parameter Specification Sheet	3-27
3.6-2	Cutting Fluid Application Method for Milling	3-29
3.6-3	Cutting Fluid Application Method for Turning	3-30
3.6-4	Cutting Fluid Application Method for Grinding	3-31
3.6-5	Cutting Fluid Application Method for Drilling	3-32
3.7-1	Photograph of a Two Compartment 400 Gallon Total Capacity Truck Mounted Sump Cleaner, Courtesy of the Master Chemical Company	3-34
3.7-2	Photograph of a 15 Inch Round Bottom Troughing with Underslung Flush Nozzles, Courtesy of Henry Filters	3-37
3.7-3	Photograph of a 15 Inch Round Bottom Troughing with Drop in Flush Nozzles, Courtesy of Henry Filters	3-38
4.3-1	Example of SEM Examination of the Tool Wear Mode for Turning.	4-4

READERS NOTE

It should be emphasized that the primary program objective has been to develop requirements for a cutting fluid control system. Accomplishment of this objective required that a series of tasks be completed. One task was to evaluate commercially available cutting fluid products such that systematic performance characteristics based on generic fluid types could be established relative to specific requirements for the Rock Island Arsenal. Another task was to evaluate the various methodologies for cutting fluid recycling and recommend one or more generic type(s) of cutting fluid recycling system(s) for the Arsenal.

Mention of specific products must not be construed as an endorsement of any kind but as an example of suitable products representative of a particular generic type.

1.0 INTRODUCTION

For the past two and one-half years, TRW's Materials Technology and Manufacturing Center has been actively researching the state of the art of cutting fluid application technology and cutting fluid recycling methods for the Rock Island Arsenal (RIA). The objective of this program is to establish a cutting fluid selection and control system based upon performance data which will improve productivity and reduce manufacturing costs in the machining areas of the Arsenal. The program has been organized as a three-phase effort, designed to take place over two and one-half years.

Phase I was designed for data gathering and analysis of the manufacturing processes at the Arsenal. A survey of the RIA manufacturing facility was conducted in order that the results could be used as a data base to develop laboratory test simulations and construct a preliminary machining severity index. A severity index is a parameter which defines the requirements of a cutting fluid based on the machining parameters and material used. The preliminary machining severity index would later be refined and used to aid the Arsenal in specifying a cutting fluid for a particular machining application. Provisions were made to allow the Arsenal to update the severity index with future machining operations. Methodologies to prescreen potential cutting fluid candidates were also developed. The Phase I program effort was published under RIA Technical Report Number EN-81-02, Establishment of a Cutting Fluid Control System (Phase I) by G. A. Lieberman.

The Phase II, or second year program effort, was a continuation and refinement of Phase I. The preliminary severity index was further developed and additional cutting fluid performance tests were performed. These tests were used to finalize a cutting fluid application matrix that may be used to select a generic type cutting fluid for a particular RIA machining operation and to develop a preliminary cost benefit analysis. The results of the Phase II program effort were published under RIA Technical Report Number EN-82-08, Establishment of a Cutting Fluid Control System (Phase II) by G. A. Lieberman.

The third phase of the program was the implementation phase. This portion of the program was highlighted by a demonstration of selected cutting fluids on RIA production equipment and RIA parts. An economic model has been developed that will allow RIA personnel to evaluate future cutting fluid candidates. Also, technology transfer of state-of-the-art cutting fluid techniques has been completed during this portion of the contract. Lastly, a recommendation for a cutting fluid control system was made along with technical briefings which reviewed the completed program with RIA management.

This report describes the work accomplished during Phase III of this program.

2.0 BACKGROUND AND TECHNICAL APPROACH

The extensive background that TRW's Materials and Manufacturing Technology Center has developed over the past decade was presented in depth in the Phase I report, "Establishment of a Cutting Fluid Control System (Phase I)," by G. A. Lieberman. The exact methodology for establishing the cutting fluid testing and evaluation program was described in the Phase II report, "Establishment of a Cutting Fluid Control System (Phase II)," by G. A. Lieberman. This section outlines the technical approach employed for Phase III of "Establishment of a Cutting Fluid Control System."

2.1 Technical Approach

The objective of Phase III of the Rock Island Arsenal's "Studies to Establish a Cutting Fluid Control System" is to provide a demonstration of selected cutting fluids as described in the Phase II program effort, create a procedure that RIA personnel can use to evaluate future cutting fluids which takes into account economic considerations, make recommendations for a cutting fluid recycling system and develop a step-by-step procedure that Arsenal personnel may follow when utilizing the severity index and cutting fluid application matrix to select a cutting fluid for a specific machining operation. In order to accomplish this, three basic steps were completed: a demonstration at the Arsenal, a vendor survey of the various types of cutting fluid recycling equipment available, and development of methods to transfer all the knowledge acquired during the three phases of the program. The following subsections will describe these steps.

2.1.1 RIA Demonstration

The purpose of the demonstration was to confirm that the cutting fluids selected through laboratory testing methods would outperform the existing cutting fluid used at the Arsenal under actual production conditions. Two new fluids were selected for the demonstration that exhibited superior performance during the Phase II testing. One fluid doubled the tool life over the production fluid used at the Arsenal for milling, and the other fluid demonstrated a 30% increase in tool life in turning operations compared to the present fluid.

The following evaluation procedure was utilized. First, tool life data were collected on a particular machining operation with the Arsenal's production fluid. Then the selected cutting fluid was tested on the same operation. Tooling samples were secured when possible to allow for exact tool wear measurements. Then the two sets of data were evaluated and the percent increase in tool life for the new fluids was calculated.

2.1.2 Cutting Fluid Recycling Systems Evaluations

There are two basic methods for recycling cutting fluids which can be candidates for application at the Arsenal: batch reprocessing or utilizing a central cutting fluid filtration system. There are many methods and equipment which exist that perform these functions as well as a multitude of manufacturers supplying them. Machining Technology, with the aid of the RIA program monitor, developed a set of specifications that was given to the various vendors of cutting fluid recycling equipment. Each vendor was requested to specify an optimal system to meet the specifications and to describe the benefits of their particular methodology. This information was then utilized to develop a recommendation for the Arsenal. It is recognized that to examine every manufacturer's cutting fluid recycling

product is impossible, but every effort was made to investigate all of the basic types of recycling equipment available.

2.1.3 Developing Methods to Transfer the Knowledge Acquired during the Three Phases of the Program

The first area of technology transfer was to present to RIA personnel the methods for using the severity index and the cutting fluid application matrix. A procedure was also developed so that Arsenal employees can select the proper generic cutting fluid for a particular machining operation. Then a procedure was developed that non-engineering personnel can utilize to compare the performance of two cutting fluids. Also, an economic model was developed that takes into consideration the significant costs of utilizing a particular cutting fluid, including indirect expenses and benefits not normally included in classic factory benefit analysis.

3.0 RESULTS AND DISCUSSION

The Phase III program results are discussed in this section beginning with the findings of the RIA cutting fluid demonstration. The Cutting Fluid Evaluation Algorithm will be presented next followed by a discussion of the Economic Model for Cutting Fluid Selection, an explanation of the projected cost savings for using the recommended cutting fluids, the results of cutting fluid compatibility tests with RIA materials, and the procedure RIA personnel will utilize to choose established cutting fluids for a particular machining operation. Finally, a section on how to select cutting fluid recycling systems will be included.

3.1 RIA Cutting Fluid Demonstration

The objective of this portion of Phase II is to show that laboratory test results are indeed reproducible in a production environment. This was accomplished by first selecting typical RIA production operations for milling and turning. TRW and RIA production management identified several representative parts. However, keeping in mind that this program was to last three years, these selections were based on 1) the probability that the parts will continue to be produced in the future, 2) frequency of occurrence, 3) severity of the operation and 4) run lengths. The two parts that were finally selected represented some of the more severe machining operations that were frequently performed at the Arsenal. This would allow baseline data to be accumulated on these parts during the first two years of the program, and later these same data will be used in the demonstration phase to compare past tool life history with the existing cutting fluids to the newly recommended cutting fluids.

The basic test procedure during the demonstration was to first take current baseline data on the machining operation using Master Chemical's Trimsol. These new baseline data were then compared to the previously collected data during Phase I and II of the program in order to determine if any changes had occurred. The same tool change criteria was used for the baseline data and the demonstration, which was the length of the flank wear scar. Tool samples were also taken for later tool wear comparisons which were conducted at TRW's research laboratory. Lastly, tests were conducted with an example fluid of the recommended generic type from the Phase II testing program. The resulting flank wear measurements obtained from the tooling inserts were compared to those taken from the baseline and the results were recorded.

The following sections will describe the turning and milling demonstration tests that were conducted during the first of several planned iterations.

3.1.1 Milling Fluid Results

The milling cutting fluid demonstration was conducted on a side milling operation of a K8449309 torque bracket which was milled on a Kearney and Trecker horizontal numerical control machining center (RIA #30510). This torque bracket is a prismatic "L" shaped part. A side milling operation was selected for studying because it was a relatively severe operation, and its past history corresponded to the currently collected data. The milling was performed with a 6.3 inch diameter staggered tooth side mill (tool #HL 41-35) with two rows of 6 teeth. Milling Specialties Triphase 4T75Q inserts were used. Initially, the 4.38 inch dimension of the torque bracket is milled to a cut that is 15.5 inches long and varies in width from 1.125 to 1.75 inches with an average depth of 0.060 inch. Also, this cutter mills an ear

5.75 inches long and 1.375 inches wide with a depth of cut of 0.040 to 0.060 inch. These cuts were milled at 318 SFM at 3 to 5 inches per minute.

Data were first collected while milling with Master Chemical's Trimsol. Four torque brackets were machined before it was necessary to change the milling cutters inserts. This corresponded to past data taken on the torque bracket during TRW's earlier Phase I and II data surveys. It was observed at that time that the side mill inserts had to be indexed after three to four pieces, with the major mode of tool failure being chipping.

The generic milling example fluid, D. A. Stuart's Dascool 502, was tested under the same operating conditions. This fluid was selected because it demonstrated superior performance during laboratory testing. The first demonstration test was designed to allow for a direct comparison between the tool inserts used with Trimsol. For comparison purposes, the three worst inserts of each demonstration test were selected and compared to each other. Very little tool wear was observed on the inserts that machined four pieces with D. A. Stuart's Dascool 502 (see Table 3.1-1) compared to the inserts used with Master Chemical's Trimsol (see Figure 3.1-1 and 3.1-2). Comparing the average flank wear measurements, a 77 percent reduction in flank wear can be suggested. However, a more accurate way of making tool wear comparison is by producing actual production parts, not by mathematical extrapolation. The demonstration tests continued in order to determine the maximum number of pieces the inserts using the Dascool 502 could produce. One demonstration test was terminated after six pieces were produced. This was a fifty percent increase in tool life. Another demonstration test was performed where eight pieces were produced before the tool inserts needed to be changed. With this second demonstration test, a tool life increase of 100% was experienced. In the demonstration tests where the six and eight pieces were produced, the tool flank wear of the three worst inserts did not exceed the tool flank wear of the three worst inserts on the tools producing four pieces with Trimsol (see Table 3.1-1). The inserts that were changed after producing six pieces probably could have run another piece; however, a conservative operator might have changed them. These facts would indicate that a 50% to 100% increase in tool life can be readily achieved utilizing a cutting fluid such as D. A. Stuart's Dascool 502.

These results were consistent with laboratory tests that predicted the doubling of tool life. However, even though the laboratory test showed the elimination of chipping as the major mode of tool failure, chipping still occurred in the demonstration test inserts. This chipping may be explained by the lack of rigidity in the tooling used. The side mill had a 8.375 inch extension which could readily develop regenerative chatter and lead to chipping.

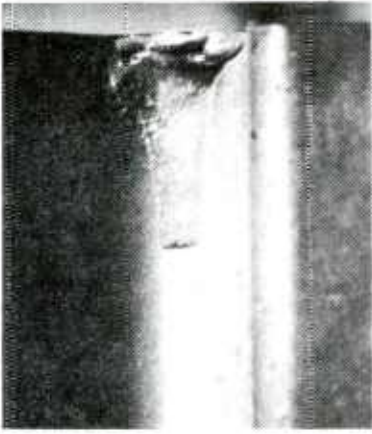
3.1.2 Turning Fluid Results

Originally, TRW was studying part #8449036 sleeve operation 070, which was machined on the American lathe #31343. During the Phase I and Phase II data gathering trips, baseline data were accumulated on this operation. This was part of TRW's plan to follow certain typical RIA parts in order to develop a part history over a two-year time period. However, during the scheduled demonstration visit, manufacturing schedules were such that part #844903 was unavailable and, hence, the demonstration had to be refocused on another application. This allowed for only a limited data base of previous part history on the newly selected part. However, the results of this limited demonstration were promising.

TABLE 3.1-1

Milling Insert Tool Wear Measurements

<u>Tool No.</u>	<u>Fluid</u>	<u>No. of Pieces Machined</u>	<u>Flank Wear (in)</u>	<u>Crater Wear (in)</u>	<u>% Reduction in Avg. Flank Wear</u>
TA	Trimsol	4	0.1137	0.0209	
TB	Trimsol	4	0.0628	0.0228	
TC	Trimsol	4	<u>0.250</u>	<u>0.0402</u>	
			Avg. 0.1421	0.0280	—
D4A	Dascool 502	4	0.0443	0.0139	
D4B	Dascool 502	4	0.0209	0.0063	
D4C	Dascool 502	4	<u>0.0330</u>	<u>0.0087</u>	
			Avg. 0.0327	0.00963	77
D6A	Dascool 502	6	0.1160	0.0215	
D6B	Dascool 502	6	0.1003	0.0438	
D6C	Dascool 502	6	<u>0.0671</u>	<u>0.0124</u>	
			Avg. 0.0944	0.0259	34
D8A	Dascool 502	8	0.1028	0.0180	
D8B	Dascool 502	8	0.0609	0.0176	
D8C	Dascool 502	8	<u>0.0594</u>	<u>0.0175</u>	
			Avg. 0.0744	0.0177	48



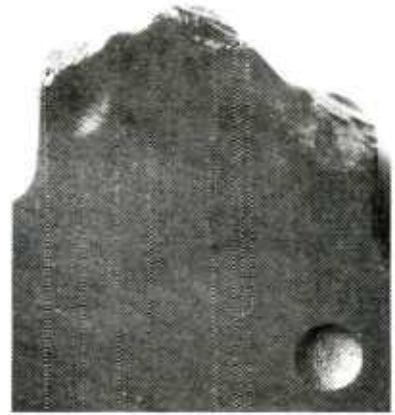
FLANK (INSERT TA)



CRATER (INSERT TA)



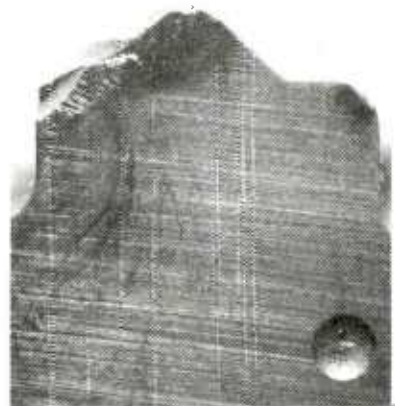
FLANK (INSERT TB)



CRATER (INSERT TB)

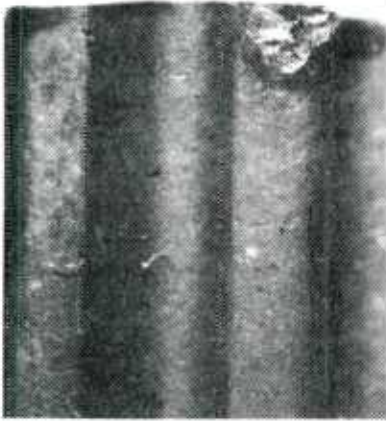


FLANK (INSERT TC)



CRATER (INSERT TC)

Figure 3.1-1. 10x photographs of milling demonstration test inserts used with Master Chemical's Trimsol after machining four parts.



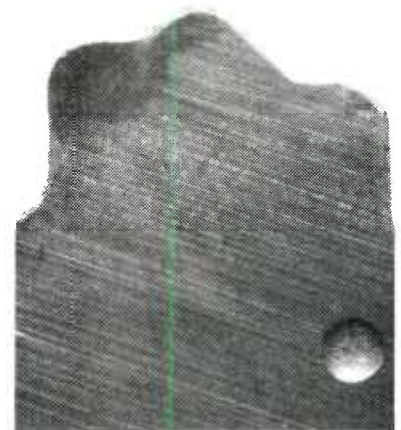
FLANK (INSERT D4A)



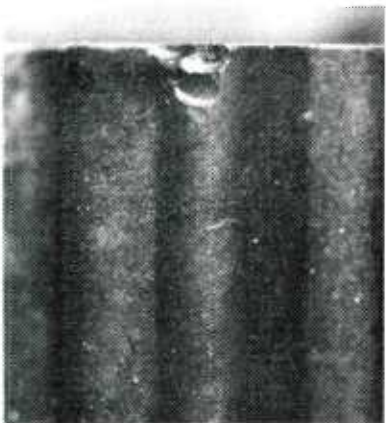
CRATER (INSERT D4A)



FLANK (INSERT D4B)



CRATER (INSERT D4B)



FLANK (INSERT D4C)



CRATER (INSERT D4C)

Figure 3.1-2. 10x photographs of milling demonstration test inserts used with D.A. Stuart's Dascool 502 after machining four parts.

The turning cutting fluid demonstration was conducted on the American lathe RIA #28029 turning part #10895646 cylinder variable recoil. Operation "turn the 7.3125 inch diameter," which uses tool position number four, was selected to be studied. This operation entailed making two recesses from the 7.770 inch diameter to 7.3125 inches, one recess being 9-3/8 inches long and the other 12-7/8 inches long. This operation was turned at 383 SFM at 6.3 inches per minute feed rate using a Sandvik TNMM-543 grade 415 insert. Operation "turn the 7.3125 inch diameter" was selected because it closely resembled the sleeve operation 070 and was the severest operation available.

The demonstration was initiated using Master Chemical's Trimsol. Initially, three pieces were machined prior to the operator wanting to change the inserts. The operator explained they normally machine three pieces prior to having to change inserts. This was to insure that the part will maintain size.

Then the machine was refilled with the generic turning example fluid, Cincinnati Milacron's Cimcool 400. This fluid was selected because of its superior performance during laboratory testing. The first demonstration test showed that five pieces could be machined with approximately the same tool wear, see Table 3.1-2. The next step was to determine the maximum amount of pieces that can be machined on the inserts using the Cimcool 400. Ten pieces were then machined on one insert edge during this maximum demonstration test trial. This required two shifts of the operation in order to machine the ten pieces. Another verification demonstration test was run; however, only seven pieces were completed during the two shifts. Additional pieces could have been machined on this insert. All of the inserts were measured for tool wear and are displayed in Table 3.1-2. Note that the tool wear for the three pieces machined with Trimsol is very close to the tool wear of the five pieces machined with Cimcool 400. This would indicate that a 66% increase in tool life can be attained with an extreme cooling,* medium lubricity* cutting fluid with a slight wetting* action such as Cincinnati Milacron's Cimcool 400.

These results were different than those predicted by the laboratory testing program. Laboratory tests indicated the Cimcool 400 should outperform the Trimsol by 30%. This increase in tool life from the laboratory tests might be explained by the fact the demonstration inserts were coated with titanium nitride and the laboratory inserts were uncoated. Coated inserts reduce the coefficient of friction between the tool and the workpiece and increase tool life. Also, the demonstration test data was based on a small sample size of data because parts were unavailable.

3.1.3 Provisions Made to Insure Demonstration Accuracy

Over the past years, TRW has been involved in implementing state-of-the-art technology in a variety of technical areas and in a multitude of manufacturing facilities. TRW has realized from this past experience the importance of taking into account certain key factors that will affect the outcome of a test conducted in a manufacturing environment. These factors are: selecting the manufacturing process and parameters, developing the technology that will optimize the selected process, conducting a controlled demonstration and developing an unbiased measuring technique which will be used to evaluate the new technology. The following will explain how these factors were taken into account during the RIA program.

Note: *The terms refer to the intrinsic qualities of a cutting fluid which was fully described in the Phase II Final Report, "Establishment of a Cutting Fluid Control System (Phase II)," by G. A. Lieberman.

TABLE 3.1-2

TURNING INSERT TOOL WEAR MEASUREMENTS

<u>Insert Code</u>	<u>Fluid</u>	<u>No. of Pieces Machined</u>	<u>Left Side Flank Wear (in)</u>	<u>Right Side Flank Wear (in)</u>	<u>Crater Wear (in)</u>
A	Trimsol	3	0.007*	0.008*	0.084
B	Trimsol	3	0.006	0.014	0.082
C	Cimcool 400	5	0.007*	0.008*	0.079
D	Cimcool 400	10	0.008	0.030	0.085
E	Cimcool 400	7	Flank Wear Data Not Available		

* Note that the flank wear of the insert that machined three pieces with Trimsol equals the flank wear of the insert that machined five pieces with Cimcool 400.

The most important factor in implementing new technology is the selection of machining processes that are representative of the manufacturing facility. In order to determine these processes, a survey of the manufacturing facility must be completed. After these processes have been selected, data must be taken on them to develop a history that will later be used for comparison. During the RIA program, several trips were made to the Arsenal to study the typical manufacturing operations and develop a history on them. From this study and many discussions with RIA production management, the typical machining parameters were selected. These parameters consisted of feed, speed, depth of cut, chipload, etc. Also, the study indicated that the majority of the machining operations were performed on 4100 series steel. A review of past production records indicated that the majority of the manufacturing operations were turning, milling and grinding.

Developing the technology that will optimize the selected processes is the next factor to be discussed. The first step in developing the new technology is creating a laboratory test plan. This test plan must incorporate all of the selected processes and parameters as well as allow for an accurate assessment of the new technology. The test plan was developed and implemented during the first two phases of the RIA program. This work allowed TRW to understand the machining processes performed at the Arsenal and to make recommendations for the cutting fluid requirements. The recommended generic fluids provide the balance of lubricity, wetting action and cooling required for RIA machining processes.

The most difficult factor is the controlled demonstration. During the demonstration, all aspects of the manufacturing process must be controlled in order that a true measure of the new technology can be obtained. This is very difficult to accomplish in a production environment. The operator has been taught to adjust his machine to insure the production of good parts. In some instances, it has been found that an operator can inadvertently apply a placebo effect to the demonstration depending on whether he believes the new technique will be effective or not. Preparations must be made for the possibility of such an effect. During the RIA demonstration, the following items were rigidly controlled:

1. Machining parameters.
2. Carbide inserts used.
3. Material used.
4. Cutting fluid concentration.
5. Cutting fluid flow rate.
6. Equipment used.

Lastly, an unbiased measuring technique must be developed to evaluate the new technology. This technique must take into account the potential operator placebo effect. The measuring method selected for the RIA demonstration was tool wear measurements. Each carbide insert was measured for flank wear and crater wear. The carbide inserts using the current cutting fluid were compared to the carbide inserts machined with the new fluid. For example, in the milling demonstration, the carbide inserts used with the new fluid produced twice as many parts with the same wear as the carbide inserts used with the current fluid. Tool wear measurement is a quantitative method of comparing two cutting fluids.

3.2 Cutting Fluid Evaluation Algorithm

An algorithm for cutting fluid evaluation was developed to be used as a procedure that RIA personnel may follow when new cutting fluids are being evaluated. Initially, the cutting fluid manufacturer must fill out the cutting fluid questionnaire displayed in Figure 3.2-1 for a product diluted in water or the questionnaire displayed in Figure 3.2-2 if a neat oil is being evaluated. These questionnaires will provide background data which will specify what machining operations the cutting fluid is recommended for and at what dilution ratios the new fluid should be used. This is entirely based on manufacturer specifications.

Next, laboratory screening tests should be conducted to determine the fluid's residue characteristics and its ability to prevent finished parts from rusting. A test batch of fluid must be prepared to the manufacturer's specified dilution ratio for turning.

3.2.1 Rust Test

The rust test is conducted by putting 10 grams of freshly drilled cast iron chips on a piece of filter paper placed in a petri dish. Then 10 milliliters of the prepared cutting fluid solution mixed to the manufacturer's dilution ratio for turning is poured over the cast iron chips. The test samples are allowed to set for one week at room temperature. Usually if a sample begins to rust it will occur during the first day. If a fluid does allow rusting it should be discontinued from further testing.

3.2.2 Residue Test

Another initial test is the residue test. This test determines what will be left on a finished part after the water evaporates from the cutting fluid. Heavy or waxy residues could inhibit machine motions or, if a hard crystalline residue is formed, it could score delicate machine surfaces. Ten milliliters of test fluid mixed to the turning dilution ratio specified by the manufacturer is placed in a petri dish and allowed to stand at room temperature until a residue is formed. This usually takes two to five days. If a crystalline or extremely gummy residue is formed, this fluid should be discarded from further testing.

After passing the preliminary screening tests, the fluid can be compared to the currently used fluid through performance tests. Two machining tests offer good indications of how well a new test fluid will perform. In order to test a fluid for grinding, drilling, boring and turning, a lathe test must be conducted using the following parameters:

SFM:	800
Feed:	0.0153 inch per revolution
Depth of Cut:	0.050 inch
Tooling:	Negative rake uncoated carbide; for example, Kennametal TNMA - 543E, K21
Material:	4140 steel tube material through hardened to R(C) 29

FLUID CHARACTERIZATION QUESTIONNAIRE FOR PRODUCTS DILUTED IN WATER

Company Name: _____ Fluid Name: _____

1. Choose Generic Type: _____ Emulsion
_____ Synthetic
_____ Other _____
2. What are the dilution ratios for the following machining operations using 4100 steel and 6000 aluminum? (Leaving a blank space will indicate the fluid is not applicable.)

Operation	4100 Steel		6000 Aluminum	
	HSS	Carbide	HSS	Carbide
Turning				
Milling				
Grinding				
Drilling				
Broaching				

3. Are there special mixing requirements?
 _____ None _____ Premix _____ Other _____

4. To what degree will any of the following factors affect the stability of the emulsion?

	No Effect	Medium Effect	Strong Effect
Temperature	_____	_____	_____
Bacteria	_____	_____	_____
Chip Material	_____	_____	_____

5. Which of the following additive types are in the product?

_____ Sulfur	_____ Phosphorous
_____ Bromine	_____ Anti-rust
_____ Oils	_____ Anti-foam
_____ Others _____	

6. What color is this product? _____

7. How strong an odor does this product have as mixed?

None Weak Medium Strong

Figure 3.2-1. Data Collection Questionnaire Used for Products Diluted in Water.

8. Will this fluid have any of the following effects on equipment?

	<u>None</u>	<u>Slight</u>	<u>Strong</u>
Paint	_____	_____	_____
Rust Inhibition	_____	_____	_____
Lubricants	_____	_____	_____
Stain Tools/Work Pieces	_____	_____	_____
Misting	_____	_____	_____
Foaming	_____	_____	_____

9. Are there additive replenishment packages available for this product?

_____ Yes _____ No

10. What procedure must be taken to dispose of this product into a waste treatment system?

11. Describe the recommended concentration testing method.

12. What is the cost and delivery time of this product?*

<u>Break Point</u>	<u>Drum</u>	<u>Tank Wagon</u>	<u>Tank Car</u>
1	_____	_____	_____
Gallons	_____ to _____	_____ to _____	_____ to _____
Cost/Gal	_____	_____	_____
Delivery Time	_____	_____	_____
2	_____	_____	_____
Gallons	_____ to _____	_____ to _____	_____ to _____
Cost/Gal	_____	_____	_____
Delivery Time	_____	_____	_____
3	_____	_____	_____
Gallons	_____ to _____	_____ to _____	_____ to _____
Cost/Gal	_____	_____	_____
Delivery Time	_____	_____	_____
4	_____	_____	_____
Gallons	_____ to _____	_____ to _____	_____ to _____
Cost/Gal	_____	_____	_____
Delivery Time	_____	_____	_____

* Available current price listings and delivery schedules may be provided.

Figure 3.2-1. (Continued)

FLUID CHARACTERIZATION QUESTIONNAIRE
FOR NEAT OIL PRODUCTS

Company Name: _____ Fluid Name: _____

1. What is the type of base oil? _____

2. Describe the physical characteristics:

Viscosity _____ Color _____
Flash Point _____ Fire Point _____

3. Which of the following additive types are in the product:

_____ Sulfur _____ Fatty Acids
_____ Bromine _____ Phosphorous
_____ Others _____

4. Indicate which machining operations and materials that can be used with this product. (Leaving a blank space will indicate the fluid is not applicable.)

<u>Operation</u>	<u>4100 Steel</u>		<u>6000 Aluminum</u>	
	<u>HSS</u>	<u>Carbide</u>	<u>HSS</u>	<u>Carbide</u>
Turning	_____	_____	_____	_____
Milling	_____	_____	_____	_____
Grinding	_____	_____	_____	_____
Drilling	_____	_____	_____	_____
Broaching	_____	_____	_____	_____

5. How strong an odor does this fluid have?

_____ None _____ Weak _____ Medium _____ Strong

6. Will this product have any of the following effects on equipment?

	<u>None</u>	<u>Slight</u>	<u>Strong</u>
Paint	_____	_____	_____
Rust Inhibition	_____	_____	_____
Lubricants	_____	_____	_____
Stain Tools/Work Pieces	_____	_____	_____
Misting	_____	_____	_____
Foaming	_____	_____	_____

7. What procedure must be taken to dispose of this product?

Figure 3.2-2. Data Collection Questionnaire Used for Neat Oils.

8. Is it economically feasible to recycle this product:

_____ Yes _____ No

9. Describe the recommended concentration testing method.

10. Are there additive replenishment packages available for this product?

_____ yes _____ No

11. What is the cost and delivery time of this product?*

	<u>Break Point</u>	<u>Drum</u>	<u>Tank Wagon</u>	<u>Tank Car</u>
	-----	-----	-----	-----
	Gallons	_____ to _____	_____ to _____	_____ to _____
1	Cost/Gal	_____	_____	_____
	Delivery Time	_____	_____	_____
	-----	-----	-----	-----
	Gallons	_____ to _____	_____ to _____	_____ to _____
2	Cost/Gal	_____	_____	_____
	Delivery Time	_____	_____	_____
	-----	-----	-----	-----
	Gallons	_____ to _____	_____ to _____	_____ to _____
3	Cost/Gal	_____	_____	_____
	Delivery Time	_____	_____	_____
	-----	-----	-----	-----
	Gallons	_____ to _____	_____ to _____	_____ to _____
4	Cost/Gal	_____	_____	_____
	Delivery Time	_____	_____	_____
	-----	-----	-----	-----

* Available current price listings and delivery schedules may be provided.

Figure 3.2-2. (Continued)

Fluid Application: Single pipe 1 inch diameter flowing at 4 gallons per minute

Test Run Criteria: Run test to 0.030 inch of flank wear

These turning tests should be conducted as follows: care must be taken to clean up the test bar and remove any decarb left on the bar from the heat treating process. This can usually be accomplished by turning off one-half inch from the diameter. The last cut should be a finishing cut in order that the tests will have a uniform diameter for starting. The currently used fluid is put into the freshly cleaned machine sump. Flank wear measurements must be taken after every one-half inch of feed travel. A toolmaker's microscope will be helpful in making these measurements. These data should be recorded on the special data sheet (see Figures 3.2-3 and 3.2-4) and plotted on the graph as it is taken. The test continues until 0.030 inch of flank wear is measured. After the currently used fluid is tested, another cleanup pass is made in order to true the test bar. The machine sump is cleaned and the new fluid is added mixed to the manufacturer's specified dilution ratio. The test proceeds in the same manner with flank wear measurements being taken at every one-half inch interval and placed on the special data sheet and graph. After the new fluid test is finished, the data sheet is completed. First a linear regression is computed using a hand calculator on the data taken during the performance testing. The slope and intercept are calculated. Then by further completing the mathematical calculations outlined on the data sheet, the total metal removed for each fluid is calculated. The fluid with the highest value for total metal removed and the smaller slope is the superior fluid. In order to determine the tooling effect produced by a new turning cutting fluid, the percent increase or decrease in tooling cost (% TC) should be calculated. The exact procedure for accomplishing this is presented in Figure 3.2-3. A negative value for %TC indicates that a decrease in tooling cost is expected. If a twenty percent decrease in tooling cost or greater is calculated, the fluid should be tested under production conditions.

New milling fluids may be tested utilizing the following milling parameters:

SFM: 370

Chip Load: 0.005 inch/tooth

Depth of Cut: 0.050 inch

Tooling: A milling cutter using a single uncoated insert;
for example, Valenite SNEA-432, VC55 insert

Cutter Diameter: 1.5 inches

Material: 4140 steel block through hardened to R(C) 29

Test Block Size: 1.6 inch wide x 6 inches long x 2 inches high

Fluid Application: Two fluid nozzles 1 inch diameter supplying 4 gallons per minute

Test Criteria: The test will continue until 0.010 inch of flank wear.

RIA CUTTING FLUID TURNING PERFORMANCE DATA ANALYSIS SHEET

CUTTING FLUID _____ DATE _____

TEST DATA

TEST INTERVAL	FLANK WEAR
.5"	
1.0"	
1.5"	
2.0"	
2.5"	
3.0"	
3.5"	
4.0"	
4.5"	
5.0"	
5.5"	
6.0"	
6.5"	
7.0"	
7.5"	
8.0"	
8.5"	
9.0"	
9.5"	
10.0"	
10.5"	
11.0"	
11.5"	
12.0"	
12.5"	
13.0"	
13.5"	
14.0"	
14.5"	
15.0"	
15.5"	
16.0"	

TEST INFORMATION

DIAMETER OF TEST WORKPIECE _____
 FEED RATE OF TEST IN IPR _____
 SFM OF TEST _____
 RPM OF TEST _____
 DOC OF TEST _____

TEST RESULTS CALCULATIONS

1. CALCULATE THE LINEAR REGRESSION FOR THE TEST DATA (USE HAND CALCULATOR)

$$y = m x + b$$

$$m = \text{SLOPE} = \underline{\hspace{2cm}}$$

$$b = \text{INTERCEPT} = \underline{\hspace{2cm}}$$

2. CALCULATE TOTAL METAL REMOVED

$$X = \frac{.030 - b}{m} = \frac{.030 - \underline{\hspace{1cm}}}{\underline{\hspace{1cm}}} = \underline{\hspace{1cm}}$$

$$Z = \frac{X}{\text{RPM} \times \text{FEED RATE}} = \frac{\underline{\hspace{1cm}}}{\underline{\hspace{1cm}} \times \underline{\hspace{1cm}}} = \underline{\hspace{1cm}}$$

$$\text{TMR} = Z \times 12 \times \text{SFM} \times \text{FEED} \times \text{DOC}$$

$$\text{TMR} = \underline{\hspace{1cm}} \times 12 \times \underline{\hspace{1cm}} \times \underline{\hspace{1cm}} \times \underline{\hspace{1cm}} = \underline{\hspace{1cm}}$$

COMPARISONS BETWEEN TESTS

$$\% \text{TL} = \frac{\text{NEW FLUID TMR} - \text{CURRENT FLUID TMR}}{\text{CURRENT FLUID TMR}} \times 100$$

$$\% \text{TL} = \frac{\underline{\hspace{1cm}} - \underline{\hspace{1cm}}}{\underline{\hspace{1cm}}} \times 100 = \underline{\hspace{1cm}}$$

$$\% \text{TC} = \frac{\frac{1}{\text{NEW FLUID TMR}} - \frac{1}{\text{CURRENT FLUID TMR}}}{\frac{1}{\text{CURRENT FLUID TMR}}} \times 100$$

$$\% \text{TC} = \frac{\frac{1}{\underline{\hspace{1cm}}} - \frac{1}{\underline{\hspace{1cm}}}}{\frac{1}{\underline{\hspace{1cm}}}} \times 100 = \underline{\hspace{1cm}}$$

Key: X = Distance to .030 flank wear

Z = Time to .030 flank wear

TMR = Total Metal Removed (Cubic Inches)

%TL = Percent increase or decrease in tool life

%TC = Percent increase or decrease in tooling cost

Figure 3.2-3. Turning Cutting Fluid Performance Data Analysis Sheet

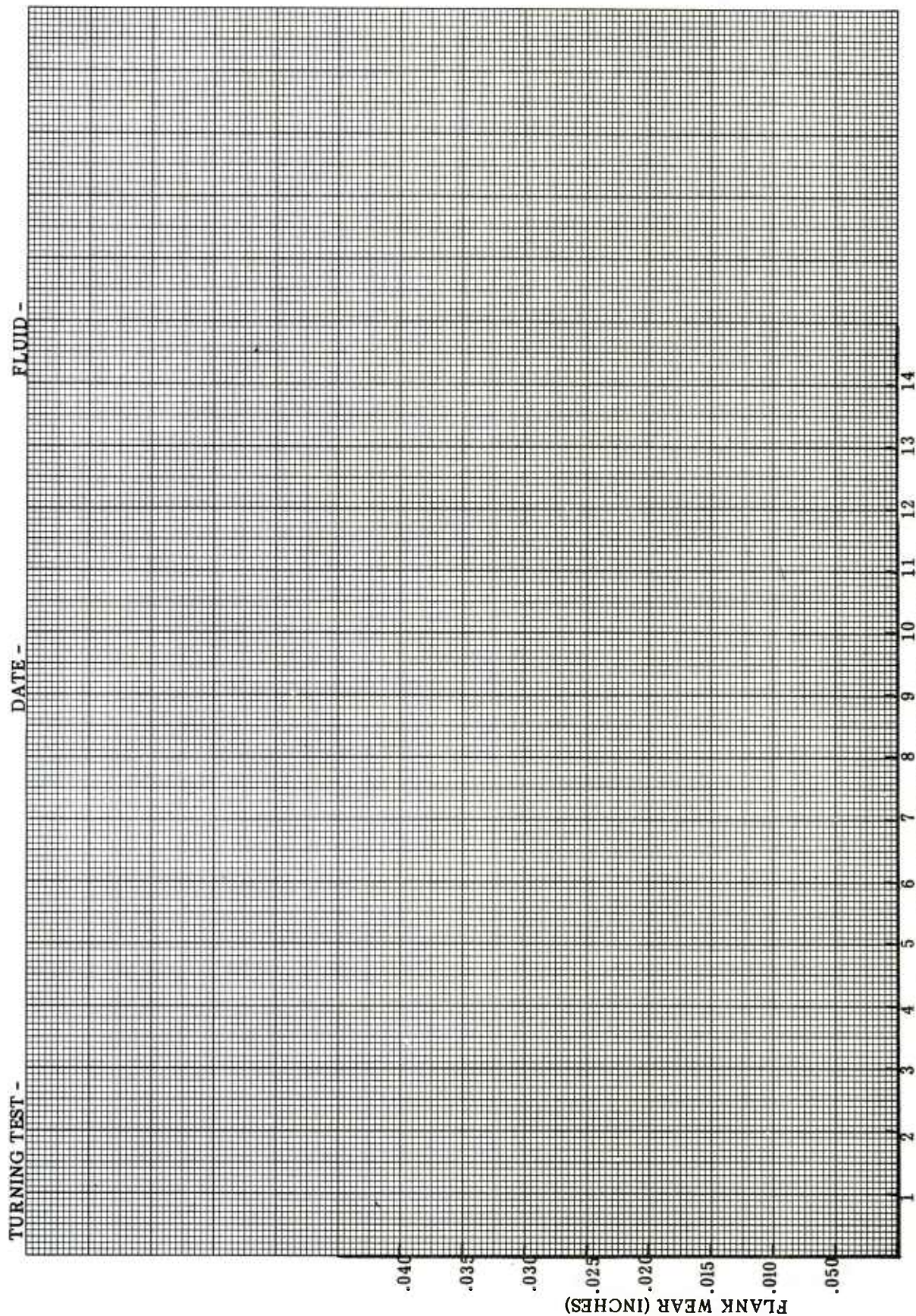


FIGURE 3.2-4. GRAPH FOR RECORDING TURNING CUTTING FLUID PERFORMANCE TEST RESULTS.

The mill should be set up with a test block of 4140 steel hardened to R(C) 29 that has a width slightly larger than that of the diameter of the milling cutter and a length about three times the cutter diameter. The milling cutter body must be balanced and have only one insert making the cut. This can be accomplished by grinding down the remaining inserts so they will not engage the test block material or purchasing a single insert milling cutter. Initially, the test block should be ground square removing all scale and decarb left from the heat treating process. The currently used cutting fluid should be added to the freshly cleaned machine sump. Flank wear measurements must be taken after the special data test sheet and graph (see Figures 3.2-5 and 3.2-6). Burrs should be removed from the test bar prior to the next milling cut with a file. The test will continue until 0.010 inch of flank wear is observed on the test insert. After the currently used fluid test is completed, the new test fluid should be added to the freshly cleaned machine sump at the manufacturer's recommended dilution ratio. This test will continue as before recording the flank wear measurements on a special data form and graph until 0.010 inch flank wear is achieved. Then a linear regression is calculated for both test fluids using a hand calculator. The slopes and intercepts are recorded in their designated spaces on the special data form. Further mathematical calculations are carried out as outlined by the form, and the total metal removed for each test fluid is calculated. The fluid having the highest total metal removed and the smaller slope is the superior fluid.

The methodology to calculate the tooling effect produced by a new milling fluid is similar to that of a turning fluid. Figure 3.2-5 provides the methodology to determine this effect. As in turning, if a twenty percent decrease in tooling cost or greater is calculated, the fluid should be tested under production conditions.

The accuracy of these test procedures may be enhanced through repetition. It is recommended that at least three replications of these procedures be performed and the results averaged. This will average out material variations, cutting tool variations and other forms of experimental error.

3.3 Economic Model for Cutting Fluid Selection

This section will present the general concept of the economic model that is contained in its entirety in Appendix A of this report. Some examples of actual calculations used to economically compare Trimsol to Dascool 502 and Cimcool 400, which may be found in Appendices B and C, will also be examined.

In order to select the optimal cutting fluid for a particular manufacturing facility, many aspects must be evaluated and compared. The benefits of using one fluid over another must be quantified and compared before a final cutting fluid is selected. The following describes the cost model detailed in Appendix A which has been developed to quantify various cutting fluid characteristics, which will allow for an accurate comparison between cutting fluids.

A defensible method to evaluate one cutting fluid to another is to compare the associated costs on a yearly basis. These costs can be broken down into the cost associated with the fluid which will be called the fluid cost and the cost associated with the use of the fluid or the manufacturing cost. The manufacturing cost will be based on tool life studies as explained in Section 3.2. The basic expression for comparing one cutting fluid to another is:

RIA MILLING CUTTING FLUID PERFORMANCE DATA ANALYSIS SHEET

CUTTING FLUID _____ DATE _____

TEST DATA

TEST BAR INTERVAL	FLANK WEAR
6"	
12"	
18"	
24"	
30"	
36"	
42"	
48"	
54"	
60"	
66"	
72"	
78"	
84"	
90"	
102"	
108"	
114"	
120"	
126"	
132"	
138"	
144"	
150"	
156"	
162"	
168"	
174"	
180"	

TEST INFORMATION

CUTTER DIAMETER _____
 FEED RATE (INCH/MIN.) _____
 DEPTH OF CUT (DOC) _____
 SFM _____

TEST RESULT CALCULATIONS

1. CALCULATE THE LINEAR REGRESSION FOR THE TEST DATA (USE A HAND CALCULATOR)

$$y = m x + b$$

$$m = \text{SLOPE} = \underline{\hspace{2cm}}$$

$$b = \text{INTERCEPT} = \underline{\hspace{2cm}}$$

2. CALCULATE THE TOTAL METAL REMOVED

$$X = \frac{0.010 - b}{m} = \frac{0.010 - \underline{\hspace{1cm}}}{\underline{\hspace{1cm}}} = \underline{\hspace{2cm}}$$

$$Z = \frac{X}{\text{Feed Rate}} = \frac{\underline{\hspace{1cm}}}{\underline{\hspace{1cm}}} = \underline{\hspace{2cm}}$$

$$\text{TMR} = Z \times (\text{CUTTER DIA.}) \times (\text{FEED RATE}) \times (\text{DOC})$$

$$\text{TMR} = \underline{\hspace{1cm}} \times \underline{\hspace{1cm}} \times \underline{\hspace{1cm}} \times \underline{\hspace{1cm}} = \underline{\hspace{2cm}}$$

COMPARISON BETWEEN TESTS

$$\% \text{TL} = \frac{\text{NEW FLUID TMR} - \text{CURRENT FLUID TMR}}{\text{CURRENT FLUID TMR}} \times 100$$

$$\% \text{TL} = \frac{\underline{\hspace{2cm}} - \underline{\hspace{2cm}}}{\underline{\hspace{2cm}}} \times 100$$

$$\% \text{TC} = \frac{\frac{1}{\text{NEW FLUID TMR}} - \frac{1}{\text{CURRENT FLUID TMR}}}{\frac{1}{\text{CURRENT FLUID TMR}}} \times 100$$

$$\% \text{TC} = \frac{\frac{1}{\underline{\hspace{1cm}}} - \frac{1}{\underline{\hspace{1cm}}}}{\frac{1}{\underline{\hspace{1cm}}}} \times 100 = \underline{\hspace{2cm}}$$

Key: X = Distance to 0.010 Flank Wear
 Z = Time to 0.010 Flank Wear
 TMR = Total Metal Removed (Cubic Inches)
 %TL = Percent Increase or Decrease in Tool Life
 %TC = Percent Increase or Decrease in Tooling Costs

Figure 3.2-5. Milling Cutting Fluid Performance Data Analysis Sheet.

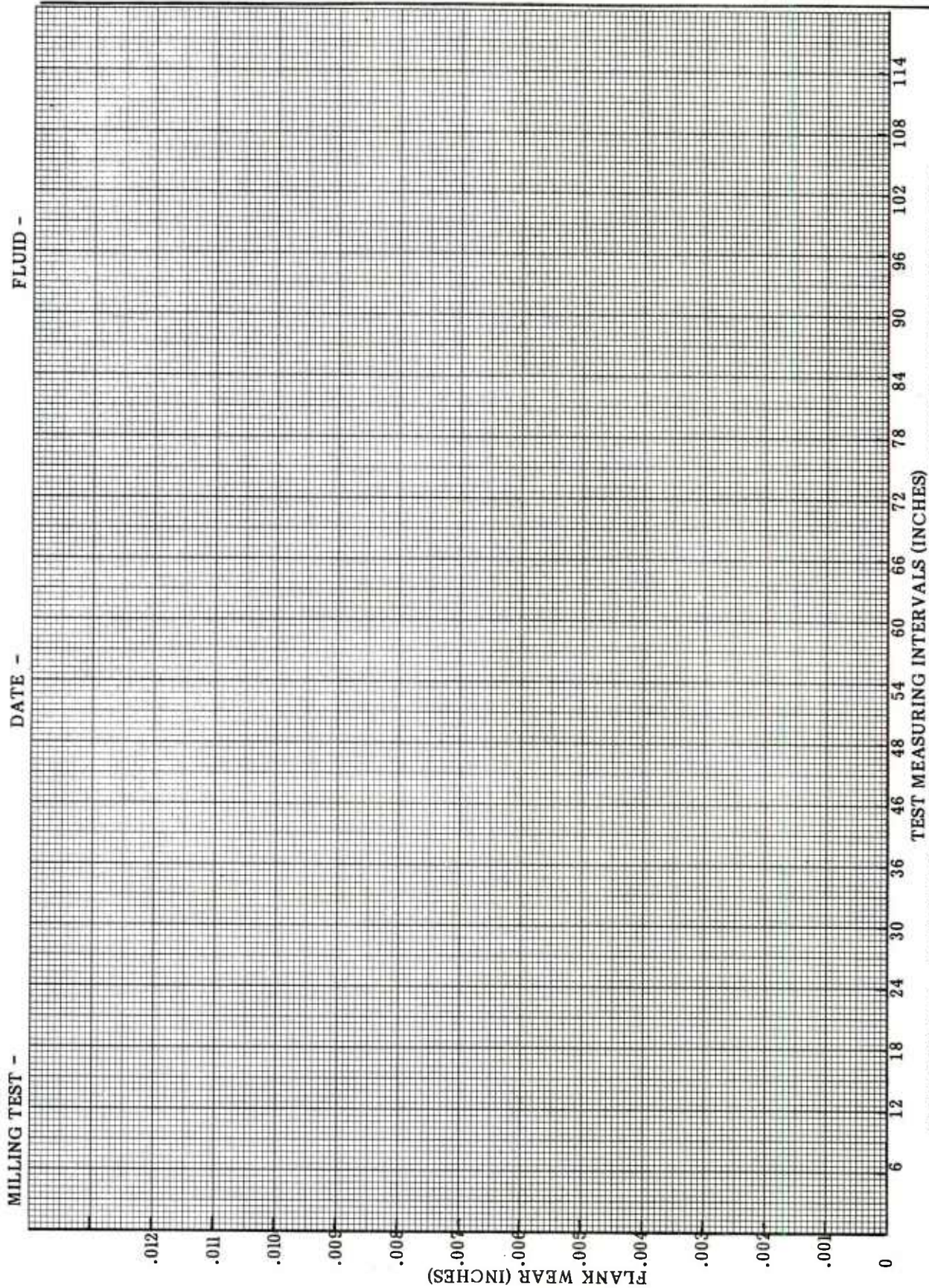


FIGURE 3.2-6. GRAPH FOR RECORDING MILLING CUTTING FLUID PERFORMANCE TEST RESULTS.

Yearly Fluid Operating Cost = fluid costs + manufacturing costs.

The fluid costs may be divided into the following elemental costs: the fluid installation cost, the fluid maintenance cost, and the fluid disposal cost. Some examples of these costs are the cutting fluid concentrate cost, the cost of water and the waste disposal cost. These values are then manipulated mathematically to calculate the resulting costs. For an example, Appendix B will be referred to which compares Trimisol to Dascool 502. In order to calculate the number of gallons of the initial charge of the cutting fluid (GIC), the number of machines (19) must be multiplied by the average sump size (50 gallons) which results in a 950 gallon initial charge. This result is used to determine the cost of the initial charge of the cutting fluid. Trimisol's concentrate cost per gallon is \$7.85 and the required concentration is 5% which results in an initial cutting fluid charge cost of \$373 for the numerical control mills in Shop M. As can be seen in Appendix A or B, many factors are taken into account in order to determine the fluid costs.

Costs associated with manufacturing may involve tooling, carbide inserts, regrind, and cutting fluid incompatibility with a particular machining material. For example, a cutting fluid's incompatibility cost will be reviewed. The data will be taken from Appendix C which compares Trimisol to Cimcool 400. Cimcool 400 produces a slight stain on aluminum adding to the cost. Past production records indicate that 24 aluminum jobs are machined per year in Shop M. The cost to clean a sump with the Cimcool 400 cutting fluid, refill it with an aluminum compatible cutting fluid, clean the sump again and refill it with Cimcool 400 has been calculated to be \$252, adding \$6,048 to the machining requirements cost.

The Economic Model that is explained in Appendix A was used to develop the following potential cost savings which are explained in detail in the Appendices.

Appendix B - Shop M N/C milling comparison of Trimisol and Dascool 502, \$141,835 potential cost savings using Dascool 502.

Appendix C - Shop M N/C turning comparison of Trimisol and Cimcool 400, \$61,664 cost savings using Cimcool 400.

Appendix D - Shop L turning comparison of Trimisol and Cimcool 400, \$378,009 potential cost savings using Cimcool 400.

3.4 Projected Cost Savings After Implementation of Recommended Generic Type Cutting Fluids

For the past two and one-half years, TRW has been evaluating potential cutting fluid candidates for the numerical control milling, numerical control turning and grinding departments in Shop M. Because of their superior performance in laboratory testing, demonstration testing and the economic model analysis, two generic types of cutting fluids have been selected. The potential yearly cost savings for these cutting fluids are presented in Table 3.4-1. A total estimated cost savings, based on the observed product mix, which has been historically constant, and other numbers provided by RIA personnel, for the example products according to the economic model is \$203,499 per year. Extreme measures were taken to obtain credible numbers from RIA personnel rather than TRW's own observations in order to provide a better estimate of actual work levels, mix of parts, tooling costs, machine idle time costs, regrind costs, chip removal time, etc. Further details of how these numbers were used are presented in the following text and Appendices B, C and D. It should be noted that specific name cutting fluids have been implemented at the Arsenal. A specific fluid was implemented because some product had to be used in order to conduct the demonstration phase of the program. The fact that a particular fluid was selected for the demonstration does not constitute a specific recommendation of that product over others in the same class but is an example of a generic product from a general class of materials.

The original goal of this program was to find a product that would operate effectively on both ferrous and nonferrous materials. One of the example cutting fluids (Cimcool 400) produces a slight black stain after prolonged exposure to aluminum. It appears that this slight staining is primarily aesthetic in nature rather than harmful to the aluminum component. However, after examining the results of the economical analysis based on Cimcool 400 compared to the currently used Trimsol, a \$61,664 per year cost savings can be achieved (see Appendix B). The economic analysis took into account the cost of cleaning out the Cimcool 400 from a desired machine filling the machine with a fluid compatible with aluminum, cleaning out the machine again and refilling it with Cimcool 400 (see Appendix C). This additional cost was multiplied by the total number of aluminum jobs expected during the year. Only 2% of all the material machined at the Arsenal is aluminum. The increase in tool life, reduction of machine idle time and increased sump life outweighed the cost of taking into account aluminum parts. This cost savings is based on conservative estimates. For example, it was assumed that the average time for tool changes is 15 minutes per shift. If this value is increased to 20 minutes per shift, the cost savings would increase another \$30,000 per year.

Also, RIA production supervision tried the Cimcool 400 in other areas with extremely good results. The production grinding department reports excellent results. Due to the lack of severity of the grinding performed in this department, performance comparisons are impractical. Cimcool 400 was tried in additional turning operations in Shop L. Shop L reported an increase in tool life from 4 to 6 pieces per insert using Trimsol to 8 to 10 pieces per insert using Cimcool 400. Tooling costs and tool change time can be reduced by 40 percent using the example cutting fluid. This is the same result that

TABLE 3.4-1

PROJECTED CUTTING FLUID COST SAVINGS

Area	Current Fluid	Recommended Generic Qualities	Example Fluid	Projected Cost Savings
Shop M Numerical Control Turning	Master Chemical's Trimsol	Medium Lubricity Extreme Cooling Slight Wetting	Cincinnati Milacron's Cimcool 400	\$61,664
Shop M Numerical Control Milling	Master Chemical's Trimsol	High Lubricity Slight Cooling Effective Wetting	D.A. Stuart's Dascool 502	\$141,835
Shop M Production Grinding	Cincinnati Milacron's 5 Star 40	Medium Lubricity Extreme Cooling Slight Wetting	Cincinnati Milacron's Cimcool 400*	Negligible Compared To Other Areas Using Con- servative Estimating
Total Estimated Savings for Shop M Using Proposed Fluids =				\$203,499
Shop L Turning	Master Chemical's Trimsol	Medium Lubricity Extreme Cooling Slight Wetting	Cincinnati Milacron's Cimcool 400	\$378,009
TOTAL RIA POTENTIAL SAVINGS				\$581,500

*This fluid exceeds the generic recommendations. However, using it for grinding will allow for one less cutting fluid. Also, its residue is better than those fluids found having the recommended generic qualities.

was obtained during TRW's demonstration. In addition, the feed rate could be increased from 0.014 inch/revolution to 0.020 inch/ revolution. The tool life for Trimsol was drastically reduced to 2 to 4 pieces per insert, while the Cimcool 400 was able to produce 6 to 8 pieces per insert at the increased feed rate. A fifty percent decrease in tooling cost was achieved by the example fluid in this case. This reduced the time to produce a piece by 3.4 minutes. The test was performed on part #12007644 which is 48 inches long using the G.F. & KDM Lathe. Kennemetal DPRA-543, KC810 titanium coated inserts were used. The machining parameters were 300 rpm, 0.014 and 0.020 ipr, 0.250 DOC, and the initial part diameter was 6.5 inches.

During the Demonstration Phase, the example milling fluid doubled tool life but left a slightly sticky residue. The operators complained of the residue, and after the one month testing program was over, they had the test machine pumped out before the D.A. Stuart Oil Company could rectify the problem. After considerable efforts were made by the program monitor, the production department tried the Dascool 502 cutting fluid again. Two additives were supplied by the manufacturer and mixed into the machine sump by the program monitor. Initially, some improvement was noticed but, before further additive additions could be made, the production personnel replaced the fluid with Trimsol. As shown in Table 3.4-1, a potential cost savings of \$141,835 per year can be realized with the implementation of this generic type of fluid. Again, this cost savings is a conservative one. For example, no reduction in tool change time was included. Currently, the D. A. Stuart Oil Company is still willing to work with the Arsenal to alleviate the stickiness problem. TRW suggests that the potential cost saving should be considered by the Arsenal and another try made with the new fluid. Also, an evaluation should be made as to what cost will be incurred if a slight stickiness does remain.

To date, the RIA Cutting Fluid Program has been focused on numerical control turning and numerical control milling because the greatest cutting fluid and recycling cost savings can be achieved in these areas. However, other lathe and mill operations exist throughout the Arsenal. The potential cost savings of the additional turning operations in Shop L can be estimated to be \$378,009 per year (see Appendix D). It is very difficult to estimate the additional savings for milling because high speed steel tooling is used. Currently, the Arsenal was unable to break down the 3 million dollar regrind costs into associated areas.

The total projected cost savings for Shop M and Shop L is \$581,500 per year.

3.5 Cutting Fluid Compatibility Test Results

During the Phase I & II cutting fluid performance evaluation phases of the RIA cutting fluid program, eighteen different cutting fluids were evaluated. These fluids were selected as generic examples of products screened from the large number of candidate products examined during the Phase I and Phase II program effort. These eighteen products were also tested for compatibility with RIA nonferrous materials. Each nonferrous material sample was sanded down, and one-half of it was submerged into the cutting fluid which was mixed to the turning dilution ratio. Each test lasted one week. However, when a fluid would cause a stain, it normally would occur during the first 24 hours of the test. The results of these tests are displayed in Table 3.5-1. The majority of the fluids tested were compatible with all RIA nonferrous materials.

3.6 Cutting Fluid Selection Procedure

This section will contain a step-by-step procedure that RIA personnel may follow when they wish to select a cutting fluid for a particular machining operation. The following

TABLE 3.5-1
RESULTS OF THE CUTTING FLUID COMPATIBILITY TESTS

Manufacturer	Fluid	Aluminum QQ-A-250	Aluminum Bronze QQ-B-679	Manganese Bronze QQ-B-728	Copper QQ-C-576	Bronze QQ-B-728
Cincinnati Milacron	Cimcool 400	Slight Brown/ Black Stain	Passed	Passed	Passed	Passed
Cincinnati Milacron	Cimcool 5 Star 40	Passed	Passed	Passed	Passed	Passed
Cincinnati Milacron	Cimfree 238	Passed	Passed	Passed	Passed	Passed
D.A. Stuart Oil	Dacool 502	Passed	Passed	Passed	Passed	Passed
Doall	470	Passed	Passed	Passed	Passed	Passed
Dubois	Lubricoolant 925	Black Stain	Black Stain	Passed	Passed	Brown/Black Stain
Economics Lab.	MX 5080	Slight Black Stain	Passed	Passed	Passed	Passed
Gulf Oil	Gulfcut HD	Passed	Passed	Brown/Black Stain	Black Stain	Passed
Master Chemical	Trimsol	Passed	Passed	Passed	Passed	Passed
Master Chemical	Trim HD	Passed	Passed	Passed	Passed	Passed
Master Chemical	Trim LC	Passed	Passed	Passed	Passed	Passed
Master Chemical	Trim 9106CS	Slight Black Stain	Passed	Passed	Passed	Passed
Mobil Oil	Vacmul 2105	Passed	Passed	Black Stain	Black Stain	Black Stain

TABLE 3.5-1 (continued)
RESULTS OF THE CUTTING FLUID COMPATIBILITY TESTS

Manufacturer	Fluid	Aluminum QQ-A-250	Aluminum Bronze QQ-B-679	Manganese Bronze QQ-B-728	Copper QQ-C-576	Bronze QQ-B-728
Norton	674	Black Stain	Passed	Passed	Slight Black Stain	Passed
Norton	811	Black Stain	Passed	Passed	Passed	Passed
Valvoline Oil	Adcool 2	Black Stain	Passed	Passed	Passed	Passed
Valvoline Oil	Adcool 3	Slight Black Stain	Passed	Passed	Passed	Passed
Van Straaten	550 P	Passed	Passed	Passed	Passed	Passed

steps will be explained: specifying the machining operation, calculating the severity of the machining operation, and selecting the proper cutting fluid.

The first step in selecting the proper cutting fluid for a particular machining operation is to define that machining operation. In order to make this as easy as possible, a form has been developed to be filled out (see Figure 3.6-1). This form requires the following information:

1. The machining operation.
2. The material to be machined.
3. The specified hardness of the material.
4. The parameters for the selected machining operation.

The severity of the operation must be calculated using a severity index number in order to specify correct cutting fluid properties. The first way to accomplish this is to find the machining operation and its parameters in Sections 3.1.4 through 3.1.8 in the report entitled "Establishment of a Cutting Fluid Control System (Phase II)" by G. A. Lieberman. However, in some instances, a new machining operation may not be defined in these sections. When this occurs, the machining severity must be calculated as explained in Section 3.1.9 of the aforementioned report. This section has a detailed example of how to calculate the severity of a boring operation. For convenience, these sections are reproduced in Appendix E.

After the severity of the process has been calculated, the proper cutting fluid may be specified. In order to accomplish this, the RIA Cutting Fluid Application Matrix Based on TRW's Laboratory Performance Tests must be consulted (see Table 3.6-1). For example, a cutting fluid must be specified for a milling operation having a severity rank of 3. First locate milling under the column called manufacturing processes. Next, go across the milling row and look under the column marked severity rank 3. From this block of data, the generic cutting fluid qualities required for this operation may be read which are high lubricity, slight cooling and effective wetting. This information is used to select the proper cutting fluid. An example of the proper cutting fluid that has these generic properties is D. A. Stuart Oil Company's Dascool 502.

The fourth step is to make sure the selected fluid is compatible with the material to be machined. This information may be obtained by consulting Table 3.5-1. For example, Cimcool 400 has been selected for turning an aluminum part. However, this fluid is not compatible with aluminum for long exposures. An alternate fluid must be selected. According to Figure 3.3-34 from "Establishment of a Cutting Fluid Control Systems (Phase II)," by G. A. Lieberman, Trimsol, which is compatible with aluminum, has 30% less performance than the Cimcool 400. The Trimsol may be a good second choice for this particular operation.

The last step is to ascertain the proper cutting fluid flow rate and nozzle configuration. This information may be taken from Figures 3.6-2 through 3.6-5. For example, the proper nozzle configuration for a milling operation is placing two nozzles on either side of the milling cutter (see Figure 3.6-2). These nozzles should be one inch in diameter and flow at 5 gpm.

RIA MACHINING PARAMETER SPECIFICATION SHEET

PART NO. _____ MACHINE: _____ DATE: _____

1. MACHINING OPERATION

- ☐ BORING
- ☐ BROACHING
- ☐ DRILLING
- ☐ GRINDING
- ☐ PERIPHERAL MILLING ☐ FACE MILLING ☐ END MILLING
- ☐ TURNING
- ☐ OTHER _____

2. MATERIAL

- ☐ 4140 STEEL
- ☐ ALUMINUM
- ☐ ALUMINUM BRONZE
- ☐ COPPER
- ☐ MAGNESIUM BRONZE
- ☐ STELLITE
- ☐ OTHER _____

3. HARDNESS

_____ R_c
_____ BHN

4. PARAMETERS

_____ SFM
_____ INCHES/REV
_____ INCHES/TOOTH
_____ DOC
_____ INFEEED
_____ CROSSFEED
_____ WIDTH OF CUTTER
_____ OTHER _____

Figure 3.6-1. RIA Machining Parameter Specification Sheet

TABLE 3.6-1

RIA CUTTING FLUID APPLICATION MATRIX BASED ON TRW'S LABORATORY PERFORMANCE TESTS

MANUFACTURING PROCESS		SEVERITY RANK 1	SEVERITY RANK 2	SEVERITY RANK 3	SEVERITY RANK 4	SEVERITY RANK 5
BROACHING	Hardness /Mat'l					Stellite
	Minimum Fluid Requirements	NPA	NPA	NPA	NPA	HL, SC, SW
	Alternate Fluid Requirement					
DRILLING	Example Fluid					Topaz 7/150 Oil Poly-Form Oils
	Hardness /Mat'l		R _C 30/4100		R _C 30/4100	
	Minimum Fluid Requirements	NPA	HL, SC, EW	NPA	HL, SC, SW	NPA
GRINDING	Alternate Fluid Requirements					
	Example Fluid		DASCOOL 502 Stuart Oil*		VACMUL (S.CL) Mobil Oil*	
	Hardness /Mat'l		R _C 30/4100			Stellite
MILLING	Minimum Fluid Requirements	NPA	SL, MC, SW	NPA	NPA	HL, SC, SW
	Alternate Fluid Requirements					
	Example Fluid		Cimfree 238 Cin. Milacron*			VACMUL (S.CL) Mobil Oil*
TURNING & BORING	Hardness /Mat'l	250BHN/4100	R _C 30/4100	R _C 30/4100		
	Minimum Fluid Requirements	ML, SC, SW	HL, SC, EW	HL, SC, EW	NPA	NPA
	Alternate Minimum Fluid Requirements					
TURNING & BORING	Example Fluid	470, DoAll*	OASCOOL 502 Stuart Oil*	DASCOOL 502 Stuart Oil*		
	Hardness /Mat'l	250BHN/4100	R _C 30/4100	R _C 30/4100		
	Minimum Fluid Requirements	ML, SC, SW	ML, EC, SW	ML, EC, SW	NPA	NPA
TURNING & BORING	Alternate Fluid Requirements					
	Example Fluid	Trimsol, Master Chemical*	Cimcool 400, Cin. Milacron*	Gulfcut HO Gulf Oil*		

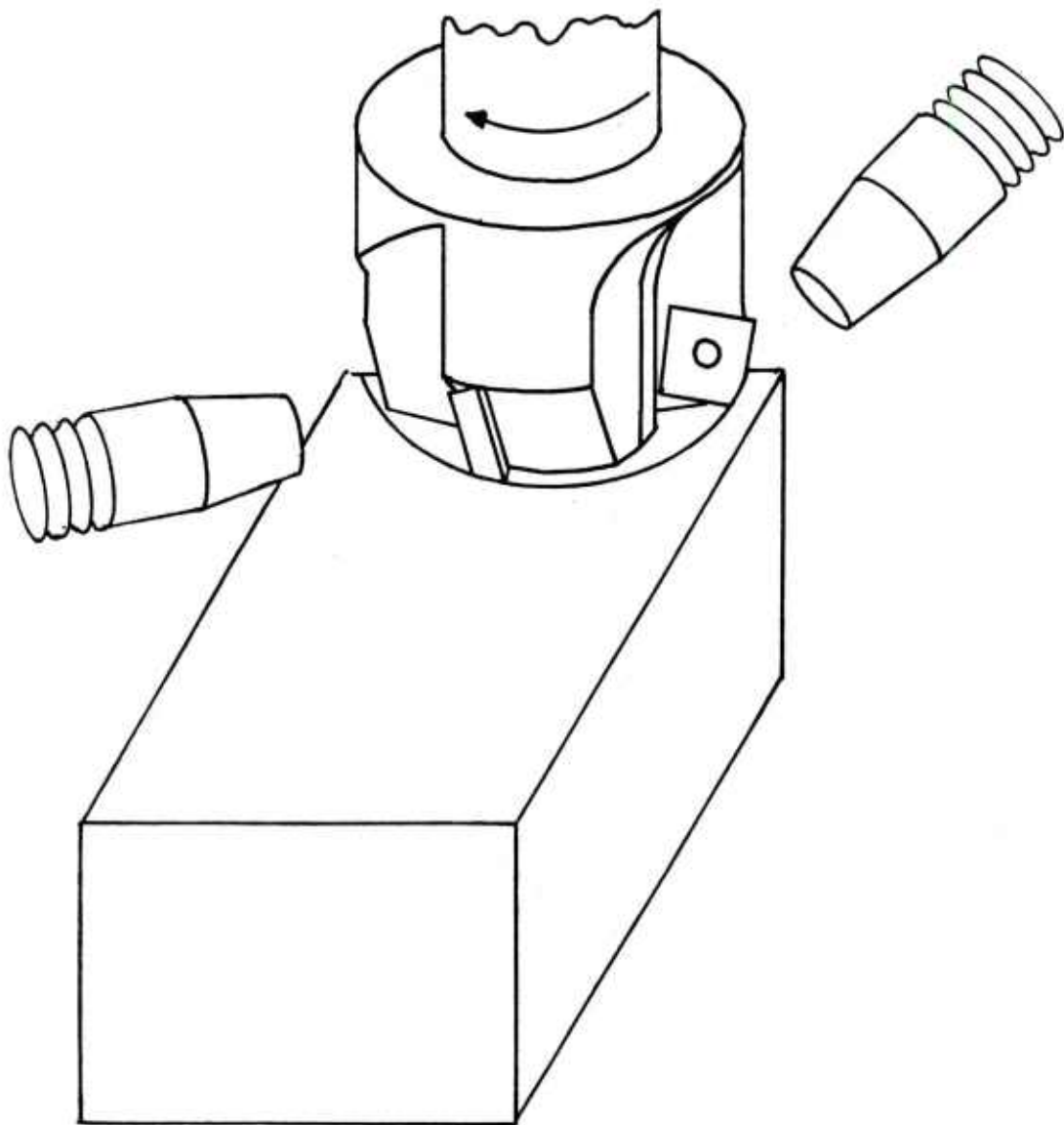
*THE FLUIDS PRESENTED AS EXAMPLES ARE NOT AN ENDORSEMENT OF A PARTICULAR CUTTING FLUID BY TRW BUT AN EXAMPLE OF A PARTICULAR GENERIC TYPE.

Wetting Action -
EW: Effective Wetting
SW: Slight Wetting
NW: No Wetting

Cooling -
EC: Extreme Cooling
MC: Moderate Cooling
SC: Slight Cooling

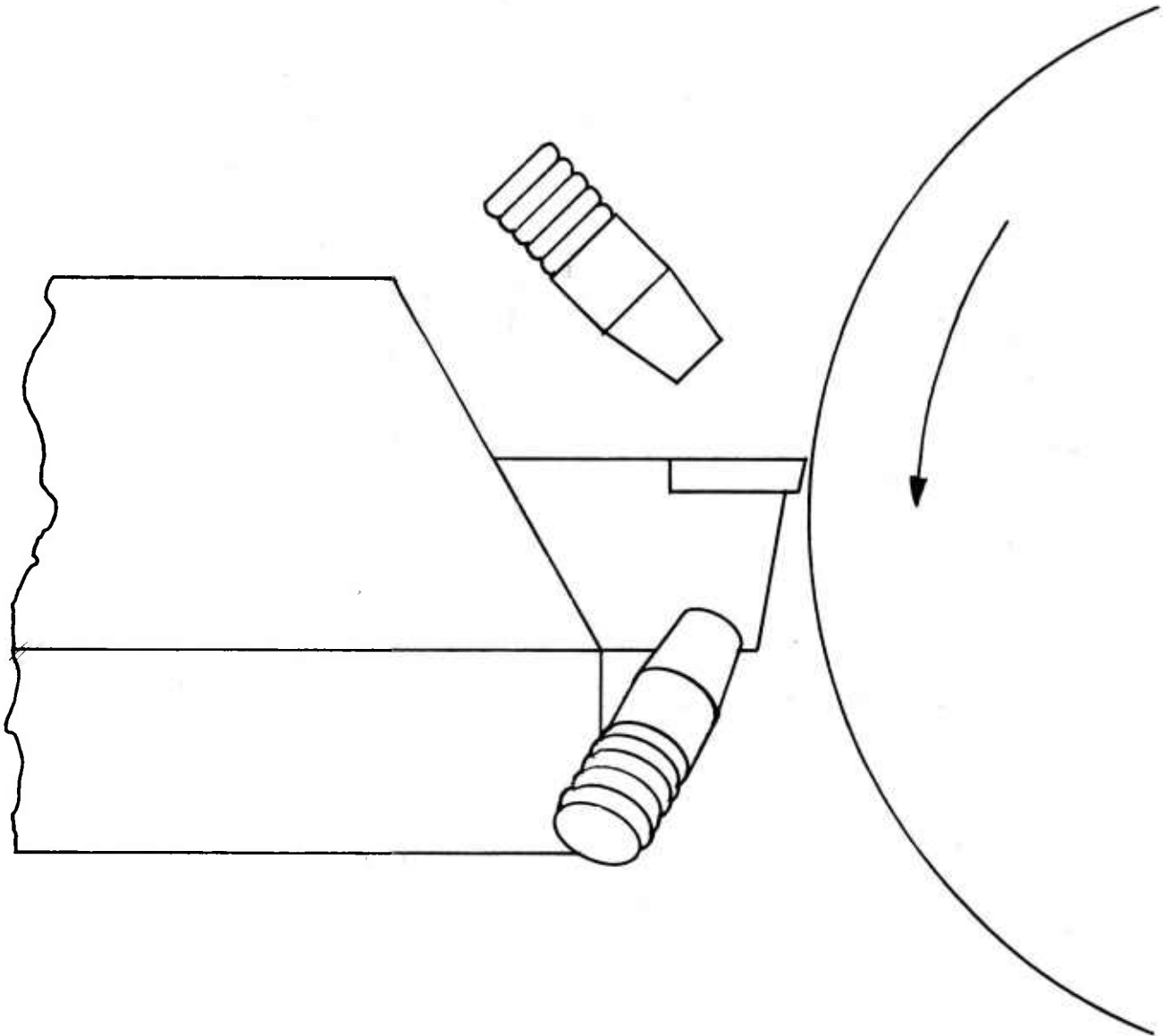
Lubrication -
HL: High Lubricity
ML: Medium Lubricity
SL: Moderate Lubricity

NPA - No process applicable



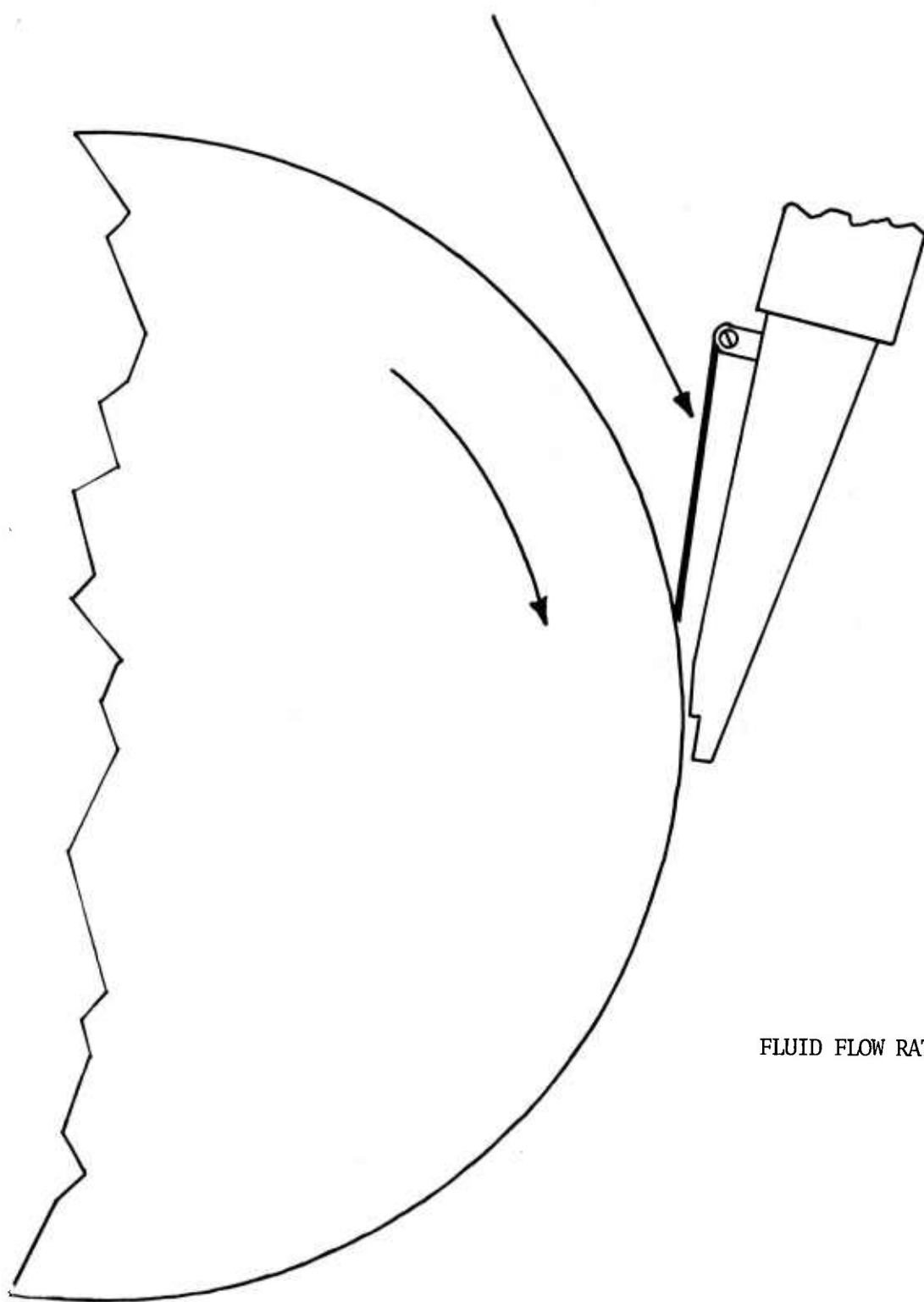
FLUID FLOW RATE IS 5 GPM FOR EACH NOZZLE @ 10-20 PSI

Figure 3.6-2. Cutting Fluid Application Method for Milling.



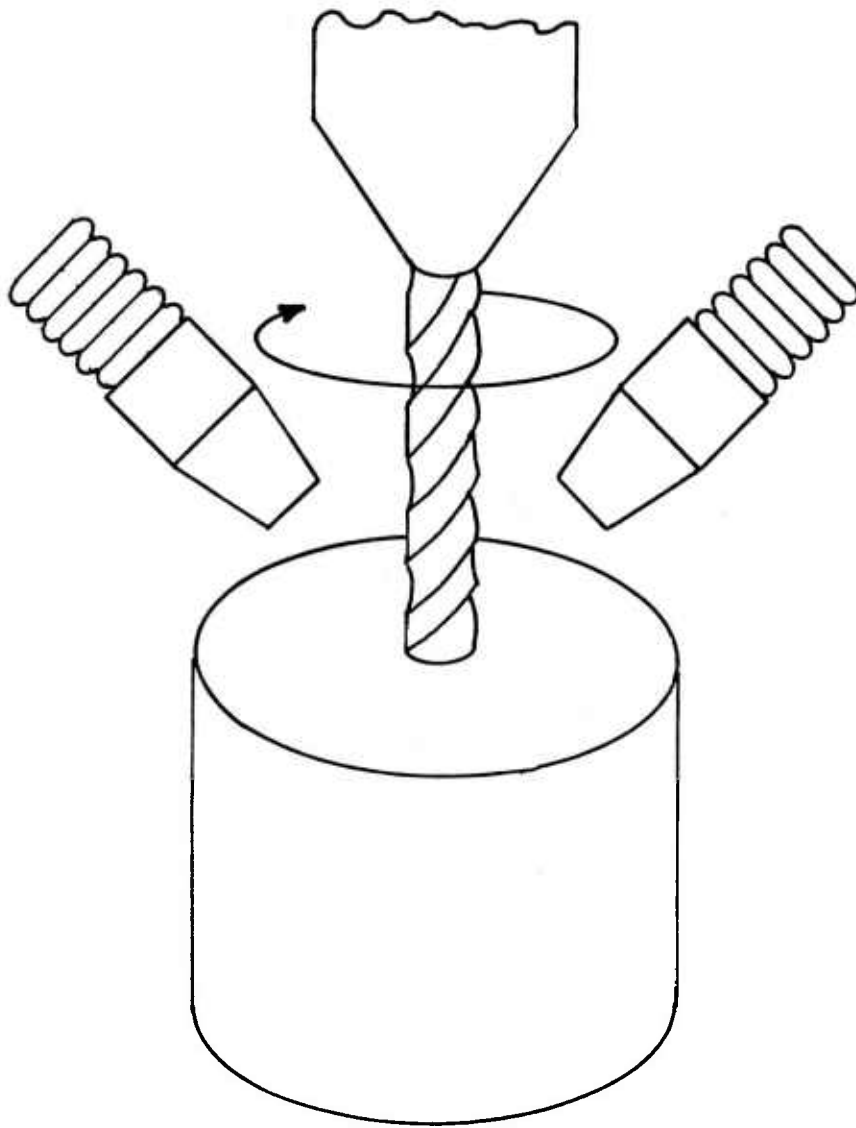
FLUID FLOW RATE IS 5 GPM FOR EACH NOZZLE @ 10-20 PSI

Figure 3.6-3. Cutting Fluid Application Method for Turning.



FLUID FLOW RATE IS 20 GPM @ 30-50 PSI

Figure 3.6-4. Cutting Fluid Application Method for Grinding.



FLUID FLOW RATE IS 5 GPM FOR EACH NOZZLE @ 10-20 PSI

Figure 3.6-5. Cutting Fluid Application Method for Drilling.

3.7 Cutting Fluid Recycling

This section will first provide some background on cutting fluid recycling. Second, a comparison will be made between batch recycling and a central recycling system. Finally, a recycling method will be recommended for the Rock Island Arsenal.

3.7.1 Background on Cutting Fluid Recycling

The purpose of a cutting fluid recycling system is to reduce the quantity of cutting fluid that has to be disposed of each year and to insure that the fluid that is supplied to the machine meets the required specifications. In order to accomplish this, a cutting fluid recycling system will remove tramp oil, remove machining chips or grinding swarf, replenish rust inhibitors, renew bacteria controlling additives, control mineral content and make corrections to the cutting fluid concentration. When this is accomplished, yearly fluid cost and waste disposal costs will be greatly reduced. Also, a reduction of tooling costs, scrap costs and machine downtime costs will be experienced.

Currently, there are two basic methods for cutting fluid recycling: 1) batch recycling and 2) a central recycling system. The following will describe the basics of these two methods.

3.7.1.1 Batch Recycling

Batch recycling is usually considered the least expensive and most versatile method for cutting fluid recycling for a manufacturing facility having individual machine sumps. This is because the capital outlay is low (typically \$65-\$120K) and the equipment required can easily be relocated. Also, many users have reported a payback period of less than one year. However, even though this type of system can generate cost savings that can pay for itself in one year, other forms of recycling may produce greater plantwide savings. This will be discussed in greater depth at the end of this section.

A batch recycling system contains four elements. The first element is the device used to pick up the spent cutting fluid from the individual machine sumps. This is normally done with some form of a sump cleaner. A sump cleaner is a portable vacuum cleaner which may contain some form of filtration media (see Figure 3.7-1). The unit is designed to remove spent cutting fluid, machining chips or grinding swarf from an individual machine sump utilizing vacuum pressure. After the machine sump is cleaned out, the sump cleaner is transported to the area where the batch recycling equipment is located. The spent cutting fluid is unloaded into the dirty tank of the recycling system. The chips or grinding swarf are placed in their designated location. Then the sump cleaner is filled with fresh fluid and transported back to machine and the empty sump is filled with the fresh fluid. Sump cleaners are made in various sizes from 100 gallons to 1000 gallon capacity. Some sump cleaners have two separate compartments: one for spent cutting fluid and one for fresh fluid. This feature will eliminate the need for two trips. Also, to minimize transportation time, sump cleaners are mounted on powered trucks instead of contained on hand push carts.

The second element of the batch method is the recycling station. This consists of a dirty cutting fluid tank, a clean cutting fluid tank, a cutting fluid clarification device, a cutting fluid proportionator, an empty drum for tramp oil collection, a supply of cutting fluid concentrate, the controls necessary to make the station operational and, in some installations, a deionized water source. This equipment is used to remove tramp oil, solid particulate contamination and bacteria.

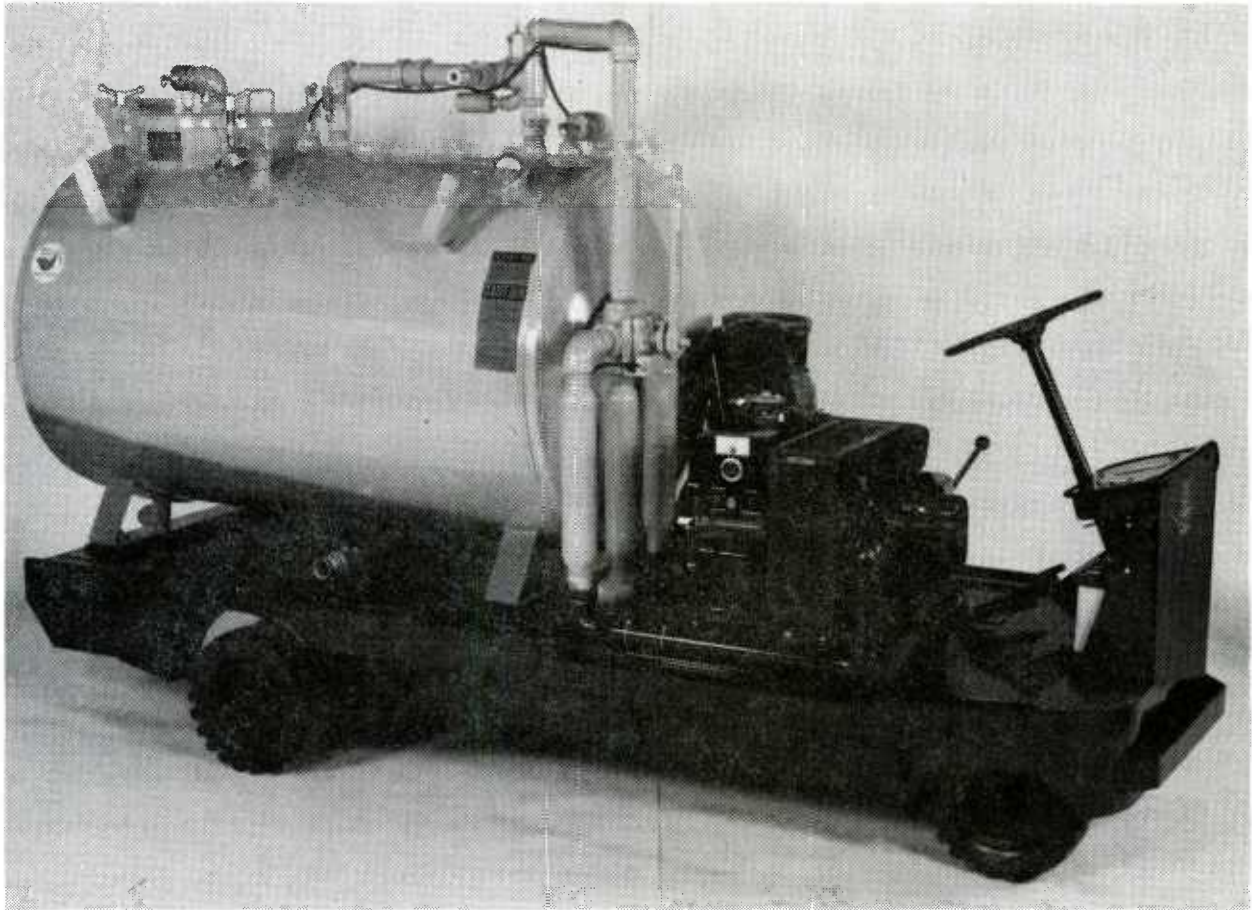


Figure 3.7-1. Photograph of a Two Compartment 400 Gallon Total Capacity Truck Mounted Sump Cleaner, Courtesy of the Master Chemical Company.

The clarification equipment is divided into two classes: separation and filtration. Separation equipment performs its clarification through the use of physical properties (i.e., differences in specific gravities). Some examples of separation devices are a gravity separator, a centrifuge, a coalescer, a magnetic separator and a hydrocyclone. See Appendix F for a definition of these devices. The other form of clarification is filtration. Filtration of a cutting fluid may be defined as the process of removing unwanted constituents through passing the fluid through a porous media. Some examples of filters are screens, vacuum filters, tube filters and pressure filters (see Appendix F for further information). The clarification device or combination of devices is the heart of the recycling station. How effective these devices are determines the cost savings of this method of recycling.

The cutting fluid mixing system and procedure is also a very important ingredient in the effectiveness of the recycling station. Basically, the mixing system mixes the reclaimed fluid with freshly made fluid in a certain proportion to a prescribed dilution ratio. For example, a cutting fluid with a 20:1 dilution ratio must be supplied to a turning operation. The recycled fluid typically comes out of the system at a 30:1 concentration. The clean tank holds 500 gallons of fluid. The prescribed procedure for this system is to mix 50% freshly mixed cutting fluid with the reclaimed fluid. This will insure that enough additives such as rust inhibitors will be in the combined fluids. Therefore, 250 gallons of a freshly mixed cutting fluid at a 14:1 concentration must first be added to the clean tank. This is accomplished by adjusting the proportionator to the desired ratio and turning on the mixer. Then the remainder of the tank is filled with reclaimed fluid coming from the clarification apparatus.

The third element of the batch recycling system is a device that will accurately measure the cutting fluid concentration. Most installations use a refractometer to measure the cutting fluid concentration. However, a titration method is more accurate because it is not susceptible to tramp oil contamination. A refractometer indicates the total amount of oil in the emulsion. If the tramp oil has been emulsified, it will also read it as part of the fluids concentration indicating a higher than actual concentration.

The last and most important element of the batch recycling method is the cutting fluid maintenance schedule and procedure. The objective of a cutting fluid maintenance program is to reprocess the cutting fluid before it has to be thrown out. This schedule will depend on what type of cutting fluid is used and the individual characteristics of the cutting fluid and the manufacturing facility. For example, a synthetic cutting fluid will have to be recycled less often than an emulsion because it is more resistant to bacteria. One emulsion will have to be recycled less often than another since it is more resistant to tramp oil. A method to develop a cutting fluid maintenance program is to carefully record data on the individual machine sumps and use this to predict the average time to recycle the cutting fluid. This data should include percent emulsified tramp oil, percent dispersed tramp oil, cutting fluid concentration, percent dissolved solids bacteria level, comments as to how the machine sump looked, how many days since last recycling and date taken. Along with the cutting fluid recycling schedule, an exact procedure will need to be developed for cleaning out a machine sump, disposing of chips or grinding swarf, operating the batch recycling equipment, maintaining the equipment, storage of supplies, disposal procedure for accumulated tramp oil, checking the cutting fluid and mixing the reprocessed cutting fluid with fresh cutting fluid.

A batch recycling system follows this general operating procedure. The sump cleaner is moved to a machine that is scheduled to be cleaned. The sump cleaner is used to

remove the dirty cutting fluid from the machine sump. Then the sump cleaner operator cleans the machine sump following an established procedure. Fresh cutting fluid is now pumped into the empty sump. This is assuming that a two-tank sump cleaner is being used. The sump cleaner operator returns to the recycling equipment area where he disposes of the machining chips or grinding swarf, empties the dirty cutting fluid into the dirty tank and fills the sump cleaner with fluid from the clean tank. This continues until all of the scheduled machines are cleaned. During the off shift or earlier, if necessary, the batch recycling equipment is turned on to recycle the dirty cutting fluid. The tramp oil and grinding swarf or machining chips are disposed of as necessary.

3.7.1.2 Central Cutting Fluid Recycling System

The central cutting fluid recycling system is generally thought of as many metal cutting machines having their used cutting fluid connected directly to a series of devices that clarify the incoming fluid and regenerate it to the original system specifications. Usually, this type of system carries away machining chips or grinding swarf from the individual machines by way of troughs and conveyors to a central chip handling system. Also, a continuous supply of recycled cutting fluid is supplied to the individual machines at the proper pressure and velocity:

A central cutting fluid recycling system may be divided into five parts: dirty fluid and chip transportation, storage of dirty cutting fluid, clarification equipment, cutting fluid maintenance and supplying fresh cutting fluids to the individual machines. Transportation of dirty cutting fluid, machining chips or grinding swarf is usually accomplished by using troughing (see Figure 3.7-2). The main advantage of a central cutting fluid recycling system is that it removes the chips and grinding swarf from a machine without the aid of the operator. This reduces the machine idle time which is the main cost reduction item this method has over the batch reprocessing method. Machining chips or grinding swarf are removed from the machine by conveyor and/or high pressure cutting fluid nozzles. These conveyors lead to steel troughs that are secured in the floor. The troughs are pitched toward a holding tank which gathers the chips. Also, high pressure flush nozzles are located throughout the trough system that push the chips or swarf to the holding tank (see Figure 3.7-3).

The second part of a central system is the holding tank for the incoming fluid and chips. This tank usually acts as a settling tank for the fluid and a collection point for the chips or swarf. During the time the cutting fluid remains in the tank, the dispersed tramp oil will float to the surface of the tank and join the free floating tramp oil. Also, the suspended fines in the fluid will settle to the bottom of the tank. The longer the fluid stays in the tank, the more tramp oil and fines will be removed from the fluid. Many central recycling systems have a system of baffles which aid in reducing the settling time required to remove the tramp oil and fines. In the bottom of the tank, a drag-out conveyor will scoop out the sludge or chips and deposit them into hoppers which may be sold to scrap dealers. In most cases, the dragout conveyor will also remove the tramp oil with the chips or swarf.

Next, the clarification part of the system will be discussed. As in the batch reprocessing there are two classes of clarification methods and many devices are available which operate these methods. Please refer to the batch recycling method if a review is necessary. In general, filtration is the most dominant means of clarification used in a central recycling system. This is due to the large volumes of fluid that must continuously flow through the clarification device.

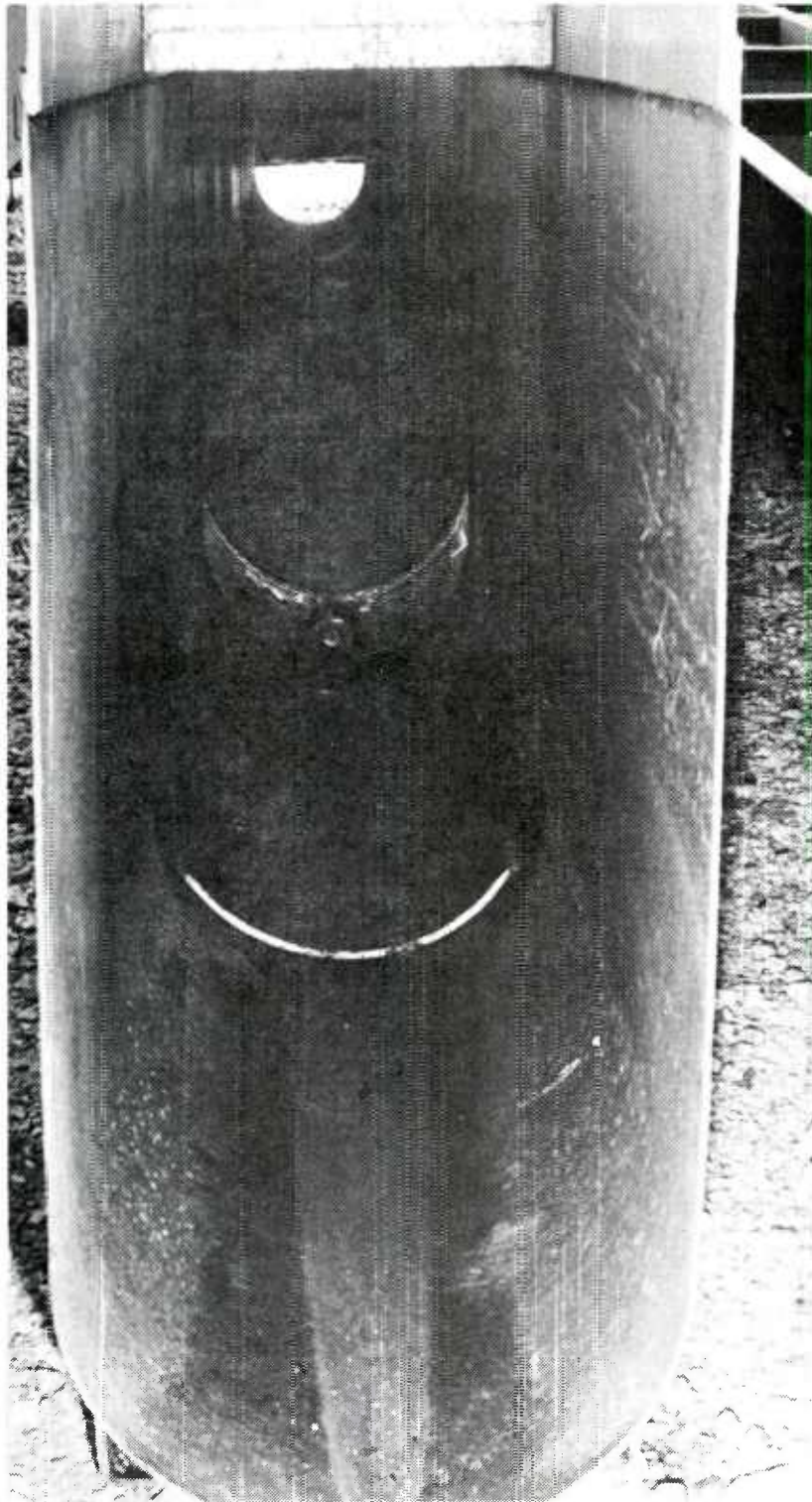


Figure 3.7-2. Photograph of a 15' Round Bottom Troughing With Underslung Flush Nozzles, Courtesy of Henry Filters.

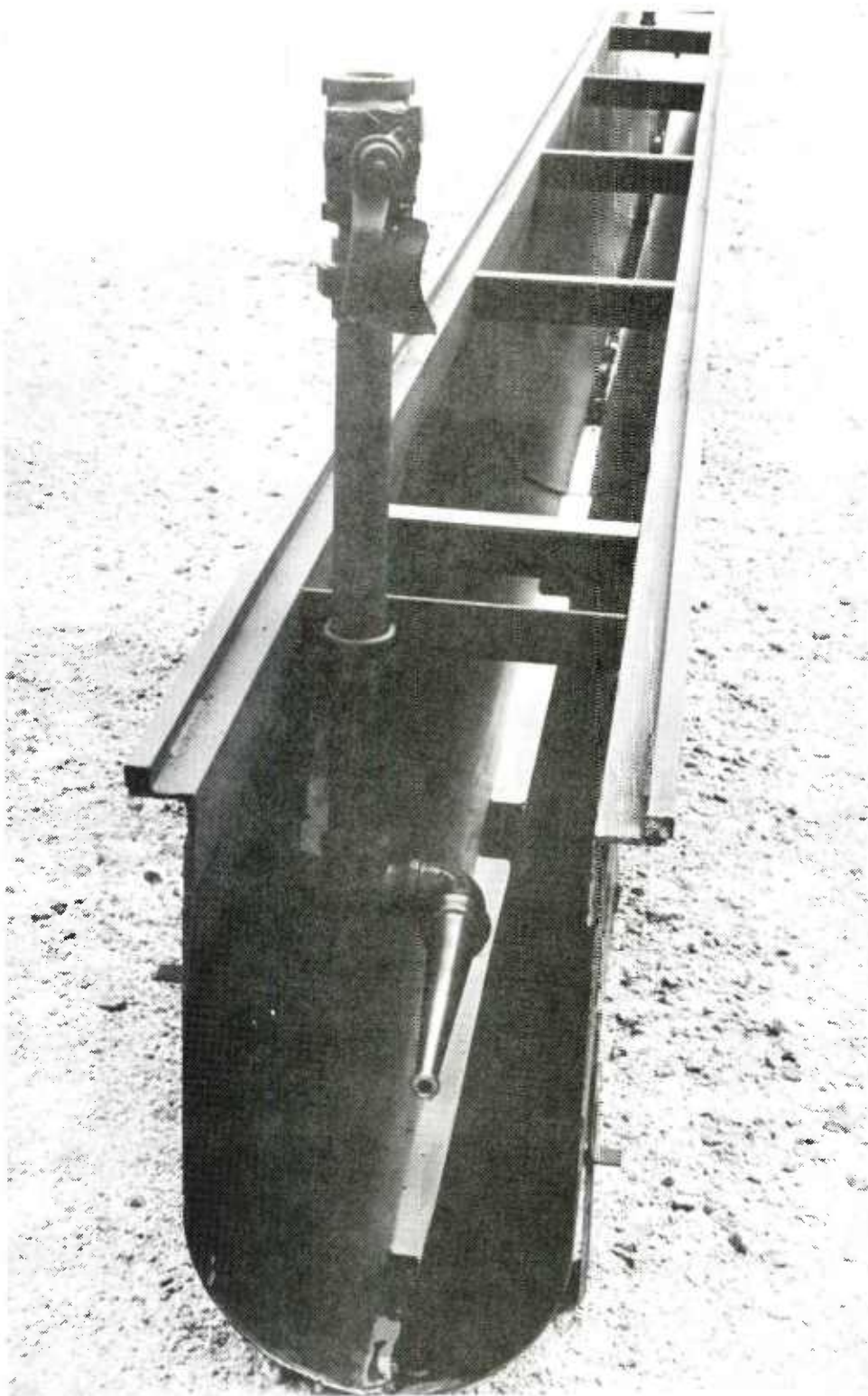


Figure 3.7-3. Photograph of a 15' Round Bottom Troughing With Drop in Flush Nozzles, Courtesy of Henry Filters.

The fourth portion of the central cutting fluid recycling system is cutting fluid maintenance. Cutting fluid maintenance is a dynamic process that should be monitored regularly. The following tests must be accomplished on a scheduled basis:

1. Titration for cutting fluid concentration.
2. Rust inhibitor level.
3. PH level.
4. Bacteria level.
5. Tramp oil analysis (free floating, suspended and emulsified).
6. Suspended solid analysis.

These tests are usually performed by a chemist who is responsible for taking corrective action when necessary. However, these tests will lend themselves to automation. A feedback control system may be developed.

Finally, the recycled fluid is pumped to the individual machines using a header system. The header and pump system is designed to provide cutting fluid to the individual machines at the desired GPM and pressure required for the specific metal cutting operation performed on the machine tool.

3.7.2 A Comparison between Batch Recycling and a Central Recycling System

In general, it is very difficult to accurately compare one cutting fluid recycling method to another in a new plant application without actually operating both systems under actual plant conditions. Some cutting fluid recycling manufacturers will allow their units to be rented and the rent applied to the purchase price. This option should be explored if enough time is available. In order to make a comparison between two different methods of cutting fluid recycling, 19 areas for comparison have been developed. These will be explained in detail in the following text.

Manpower

Manpower is the total number of manhours required to operate a particular fluid recycling method. The batch method usually requires more manpower than a central system. However, this is dependent on how many machines are involved. For example, 109 machines require fresh cutting fluid once a month. This requires five machines to be cleaned per day (109 machines/22 working days per month). It takes a laborer 1.5 hours to clean the machine sump and refill it with fresh fluid at a 7.5 hour labor cost of \$31/hour or \$233/day. A central system may require two chemist hours and two laborer hours at a total cost of \$129/day. Since the batch system requires make-up fluid to be brought to the machines at an assumed 10 minute/shift requirement for each machine, the labor cost for three shifts during a 300 working day year will be \$488,200 per year. A central system has an automatic make-up system.

Floor Space

In order to determine a value for floor space, a cost per unit area or volume must be calculated. One way of determining this is by estimating the total cost of maintaining the

building and dividing it by the total area. Another more conservative method is to find a rental building that could be used to support additional manufacturing activities. This will be the future value of space if the current facility is filled. Divide the yearly rent by the total number of square feet. This value can then be multiplied times the area of the fluid recycling method. Usually, a central recycling system is much larger than a batch system. However, central recycling systems can be installed under the floor greatly reducing the space requirements. This option increases installation cost. Great care must be taken when floor cost is calculated.

Electric Power Costs

The electric power requirements may be divided into system requirements and plantwide requirements. The system requirement is the total power required by the recycling equipment. Usually, the central cutting fluid system requires more power than a batch recycling system. For example, 61 machines have to be supplied with cutting fluid. A batch reprocessing system requires 12 hours of operation using 3 horsepower or 36 horsepower per day. To supply the same machines three shifts per day, a central system requires 130 horsepower per hour or 3120 horsepower per day. The plantwide requirements are defined as the total plant power required other than the system power. This is zero for the central system. The batch recycling method still requires the individual machine's sump pump. The power requirement for the example is, assuming 0.5 horsepower per pump, 756 horsepower per day. The total horsepower required per day by the batch method is 792 and for a central system is 3,120.

Yearly Maintenance

The cost of yearly maintenance is very difficult to estimate initially. One method of determining this is by calculating the projected costs for the second year of operation of a particular cutting fluid recycling device. Ask vendors and users what parts are needed to be replaced and how long it takes to replace them. For example, a high speed centrifuge requires its seals to be replaced once a year. The cost of this item and its labor cost can be estimated. Another method of estimating repair cost is by comparing maintenance contract costs. When calculating yearly maintenance costs be sure to include the cost of maintaining the individual machine sumps when using a batch recycling apparatus.

Cutting Fluid Costs

A central system will require more cutting fluid for an initial charge and yearly make-up than the batch recycling method. The initial charge is greater because the troughing and holding tank must be filled. More make-up fluid will be required due to the constant agitation of the fluid in the troughing and the holding tank. However, the central system's make-up concentration will be less than batch recycling, typically half. This is due to the fact that most of the loss is caused by evaporation. In the long run, the central recycling system will have less fluid costs for the following reason: in a batch recycling system, the recycled fluid is generally mixed with fresh cutting fluid on a 25% to 50% basis in order to bring up the concentration of rust inhibitor and biocide to acceptable levels. This method incurs the total cost of the cutting fluid which is about \$0.41 per gallon at 5% concentration. This means that, to fill a 50-gallon sump, \$5 to \$10 worth of fresh cutting fluid must be added. For a central system, a chemist can calculate the amount of rust inhibitor and biocide required and add these to the system. Usually, this type of addition is only fractions of a gallon. The cost of adding the biocide and rust inhibitor protection would be approximately \$1.36 for a 50-gallon sump. This same type of chemical additions could be

done on individual machine sumps for a batch recycling system, but in most cases this is impractical.

Disposable Filter Media Costs

Depending on what recycling equipment is used, a cost for filter media or some other disposable item may be incurred. For example, in a batch recycling system used for grinding, disposable bag type filters must be used to remove the small grinding wheel particles and grinding swarf. In a vacuum type central recycling system, new filter media may be constantly required. These costs must be considered.

Initial Capital Costs

The central recycling system has by far the greatest initial capital cost. The cost to service 61 machines in a confined layout may cost \$1,281,147 just for the equipment and another \$300,000 for installation. A typical centrifuge type batch recycling system with DI water system will cost approximately \$140,000 installed.

Ability to Relocate System

Central recycling systems are very costly to relocate. The troughing can not be reused if it is encased in the floor. Usually the only item that can be moved is the filtration equipment. A batch type recycling system can be easily moved from one location to another. Most systems are mounted on metal skids that have been designed so a lift truck can move them.

Plugging of Cutting Fluid Nozzles

Clogging of delivery nozzles may occur quite often in a metal cutting operation with a batch recycling system. Chips will tend to be sucked through the individual machine's sump pump and lodge in the cutting fluid line. A central system delivers filtered fluid to a machine's cutting fluid nozzle.

Tool Life

Tool life will normally be better with a central recycling system for the following reasons. Tramp oil is removed from the fluid prior to its being applied to the chip/tool interface. The less tramp oil that a cutting fluid has, the better it will perform. Tramp oil will cause a reduction of the wetting ability of a cutting fluid. If the tramp oil is emulsified by the cutting fluid, its particle size will be increased and the fluid's penetration ability will be reduced. With a central system, the cutting fluid applied to the chip/tool interface will be at the specified concentration at all times. This will insure that the necessary lubricants will be available. The tramp oil level of the fluid being circulated to a machine by a central system will be much less than an individual machine sump after one week of use. Also, the cutting fluid will be free of small particles that will tend to load grinding wheels and cause an increase in dressing frequency.

Number of Fluids that Can Be Used

A central cutting fluid system can only be used with one cutting at one concentration at a time. Two fluids at different concentration can easily be used with a batch recycling system.

Handling Repairs

Repairs to a central recycling system must be made on the off shifts or weekends. If the central system goes down, no fluid will be available to the machines. This is why most central systems are designed with backup equipment. A batch recycling system may be repaired any time.

Concentration Control

The concentration control of a central recycling system is far more accurate and consistent than batch recycling. A central system's concentration is controlled at one point where the batch method has many individual machine sumps to be maintained. Also, most central systems have a chemist performing a titration to determine the system's concentration which is a more accurate method of cutting fluid concentration measurement than a refractometer. Usually, a refractometer is used by a laborer to determine the concentration of individual machine sumps found in batch recycling. The accumulation of tramp oil tends to make a refractometer read high and/or difficult to read. Many titration procedures are too difficult to be performed by a laborer. A central system can only have one cutting fluid concentration where batch recycling may have many different ones.

Bacteria Control

A central recycling system makes bacteria control easier for the following reasons:

1. There is only one location to make additions of biocides.
2. The cutting fluid is in constant motion which provides aeration. This reduces the anaerobic bacteria level.
3. Individual machine sumps tend to grow bacteria at a faster rate because they are seldom thoroughly cleaned and may not be used for all three shifts.

Tramp Oil Control

A central system has a lower level of tramp oil than a batch system because its tramp oil is constantly being removed. An individual machine sump will accumulate tramp oil until its scheduled recycling.

Fines Removal

A central system has a lower level of fines than batch recycling for the same reasons it has a lower level of tramp oil.

Machine Locations

A central recycling system must have its machines located as close to the system as possible. However, batch recycling has no limitations for machine locations.

Chip Handling Cost Savings

The most important cost to consider when comparing a central recycling system to batch recycling is the cost that is incurred for removing chips. For example, at RIA it has been estimated that 0.5 hours are required per shift to dispose of chips. This estimate was

based on discussions with RIA Production Management, the project monitor and observations made by TRW throughout the three year program. A batch recycling method will still require this chip handling. However, a central recycling system will eliminate this need. The cost savings for 61 machines operating 3 shifts for 300 days per year based on 0.5 hour per shift downtime is \$1,305,522.

Cutting Fluid Cost Savings

One of the major justifications for installing a cutting fluid recycling system is the reduction in fluid and waste disposal costs that are generated per year. For example, 61 machines having a sump capacity of 50 gallons have to have their sumps cleaned out once a month. The mixed cost for the cutting fluid is \$0.41 per gallon and the waste disposal cost is \$0.14 per gallon. A cost savings of \$1,678 per year will be generated.

3.7.3.2 Procedures To Be Used by the New Cutting Fluid Recycling Systems

The various procedures for titrating for cutting fluid concentration and determination level of rust inhibitor must be given for the recommended cutting fluids. These procedures will be displayed in Appendix G. A mathematical formula for calculating the amount of cutting fluid at a particular concentration to bring a cutting fluid system to the correct concentration level will also appear in Appendix G along with a procedure to determine the concentration of suspended solids in the clarified fluid.

4.0 CONCLUSIONS

As a result of Phase I, Phase II and Phase III's activities, a series of conclusions and observations have been developed which can be conveniently subdivided into the following categories: RIA manufacturing processes and materials, RIA current cutting fluid system, fluid testing conclusions, demonstration conclusions and cutting fluid recycling conclusions.

These categories as they apply to the overall manufacturing operation being conducted at the Rock Island Arsenal will be treated individually in the following subsections.

4.1 RIA Manufacturing Processes and Materials

- A. Ninety-one percent of RIA manufacturing are comprised of four processes.

Ninety-one percent of all the manufacturing processes at the Arsenal are turning and boring, milling, drilling and grinding. This figure is based on monthly operating hours.

- B. Ninety-five percent of all parts in the observed machining operations were manufactured with 4100 series steels.

During the visits to RIA, seventy-six machining operations were observed on twenty-four different parts. Over 95% of these operations were manufactured with 4100 series steels. Some bronze machining was observed being done for wear surfaces. This operation seemed to require metallurgical process optimization rather than cutting fluid improvements. An extremely minor amount of aluminum and cast iron machining is performed at RIA.

- C. Chipping and cratering were the observed tool wear modes.

Seventy-five percent of the observations for turning and boring exhibited either extreme wear due to chipping or extreme wear due to cratering without evidence of flank wear or BUE effects. All of the observed carbide insert wear for milling was in the form of chipping. The turning operations observed exhibited chipping and extreme crater wear.

- D. The majority of machining operations were performed at state-of-the-art parameters.

Most of the N/C turning and milling operations were performed well beyond Machinability Data Handbook type machining parameters. These operations utilized the most advanced tooling available. Also, the foremen in the conventional machining areas were well informed about the latest tooling and machining parameters and used them where possible. Their only limitations are the older equipment they must utilize.

4.2 RIA Current Cutting Fluid System

A. RIA Needs some form of cutting fluid recycling system.

Currently, it is estimated that RIA is using 7,558 gallons of water-base cutting fluid and 4,556 gallons of neat oil cutting fluid a year. Also, 15,000 gallons of spent cutting fluid must be disposed of each month. This volume of new cutting fluid input and the present rate of disposal indicates that installing some form of recycling system would be an appropriate course of action.

As of December 1981, RIA purchased a centrifuge-type batch processing cutting fluid reclaiming system. This system became operational in the second quarter of FY 83.

B. Anerobic bacteria is the main reason for cutting fluid sump changes.

One result of the manufacturing survey indicated that the main reason for changing a machine's sump was that it emitted a foul odor. Not one person interviewed ever heard of anyone seeing an emulsion split. This indicates that the anerobic bacteria are causing GOOD cutting fluid not to be fully utilized and these bacteria must be controlled.

C. Cutting fluid concentrations are not at the manufacturer's recommended levels.

The data obtained to date seem to indicate improvements in manufacturing operations at Rock Island Arsenal can be achieved through modification of the present cutting fluid selection and maintenance systems. For example, the concentration level of the Master Chemical product Trimsol and the Cincinnati Milacron product Cimfree 238 have been utilized below the manufacturer's suggested concentration levels in many of the observed machine sumps. This problem may be attributed to one or a combination of the following:

1. Selecting a make-up fluid concentration that is too lean for the type of fluid loss.

There are three main types of fluid loss: chip dragout, splashout and evaporation. Evaporation is a natural process that removes water from the sump leaving the fluid concentrate which causes the remaining fluid to carry a higher cutting fluid concentration level than the initial charge. Dragout and splashout remove water and concentrate together leaving the remaining fluid at its current concentration level. Each of these conditions requires a different concentration make-up fluid to bring the sump to the desired level.

2. Utilizing an inaccurate method to mix the make-up fluid.

The make-up fluid mixture may unknowingly be mixed too lean by the Venturi type mixing system currently in operation.

3. Contamination oils and/or bacteria may be diluting the sump concentration.

Tramp oils and bacteria have the ability to reduce the effectiveness of the cutting fluid which causes it to perform as if it lacks concentration (refer to Section 3.3.1 of the Phase I report for clarification).

4. Utilizing an inaccurate method of measuring cutting fluid concentration.

A refractometer may not always be an accurate method to determine fluid concentration. Contaminants may become emulsified into the oil which make it appear to contain a higher than actual concentration. Also, a refractometer may not be recommended with all cutting fluids. For example, the Cincinnati Milacron Company recommends titration as the most accurate method of concentration measurement for Cimfree 238. Section 5.0 will make recommendations which have the potential to alleviate the problems.

4.3 Fluid Testing Conclusions

A. All of the turning carbide tools tested failed due to flank wear.

As illustrated in Figure 4.3-1, insert chipping or excessive crater wear did not cause the test tools to fail. The only source of tool failure was flank wear. In general, a good balance between crater wear and flank wear was observed. This is contrary to the observed tool wear modes experienced at RIA, which involved chipping and crater wear failures. TRW's machining tests were all conducted at the manufacturer's recommended concentration levels. The majority of the machine sumps observed at RIA had much lower concentration levels. A logical deduction is: as the concentration of a cutting fluid decreases below its recommended level, tool wear will increase. This is based on the fact that, for the most part, the cutting fluid tests were conducted utilizing the same machining parameters and employing the same cutting fluids used at RIA.

B. Milling is a lubrication sensitive process.

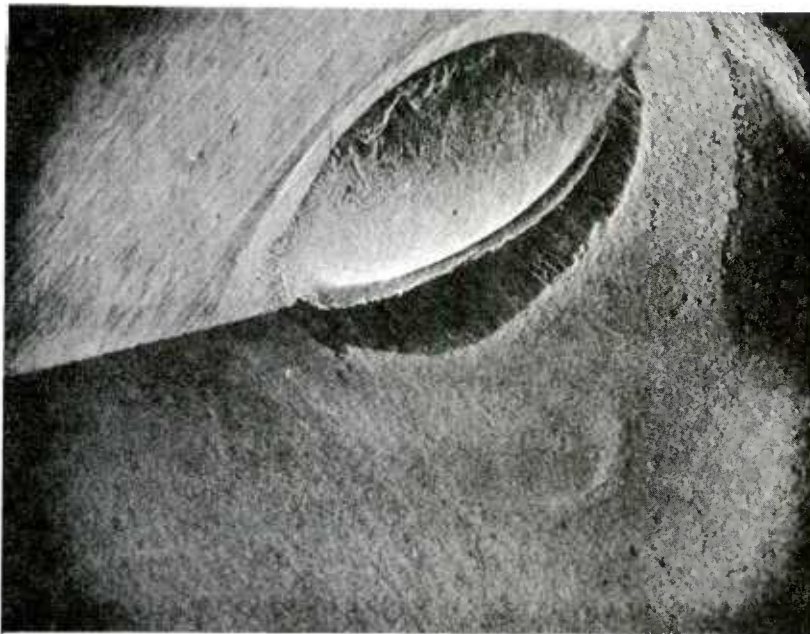
The milling tests proved that the RIA machining parameters require the following properties in a cutting fluid:

1. A high degree of lubrication.
2. Only a slight amount of cooling.
3. An effective wetting agent.

The current cutting fluids used at the Arsenal do not possess all of these properties.

C. Turning is a temperature sensitive process.

All of the cutting fluids that performed well in the turning tests had one thing in common. They all had properties that would reduce the temperature of the process.



Turning Test: Tool 4-A-11; SEM 30X; This Test Used Cincinnati Milacron's Cimcool 400.

Figure 4.3-1. Example of SEM Examination of the Tool Wear Mode for Turning.

D. Approximately 90% of all the water-soluble cutting fluid applications can be filled by two cutting fluids.

Phase II's cutting fluid performance tests indicate that different cutting fluid properties are needed for milling than for turning. Milling requires a cutting fluid that has high lubrication properties with the minimum amount of cooling while turning requires a fluid that has extreme cooling properties. The turning fluid can then be used for grinding.

E. Fluid flow rates affect machining performance.

During the grinding test, a 24% increase in power and as much as a 25% increase in forces were experienced with a slight decrease in fluid flow. Also, in turning a 27% decrease in cubic inches of metal removed to 0.030 inch of flank wear was observed during a test conducted with a slight reduction in fluid flow.

F. Cutting fluid manufacturer's classifications can be misleading.

An important finding of the machining tests was that the cutting fluid manufacturer's ranking system for their cutting fluid can be misleading. This is why the Cutting Fluid Application Matrix (Table 3.6-1) was designed to use generic cutting fluid data based on RIA manufacturing operation severity with its own definitive terminology.

G. Eight fluids showed signs of rusting during the fluid evaluation tests.

During the rust test, the following fluids showed signs of rusting: Cimperial 1011, Cincinnati Milacron; IRMCO 103, International Chemical Company; Wheelmate 811, Norton Company; Poly Aqua, Poly-form Oils; 911, Wynn Oil Company; 1149, D. A. Stuart Oil Company; Norsol S090, McGean; and Jon Cool 800; Johnson Wax.

4.4 Demonstration Conclusions

A. Laboratory tests can indeed be used to predict a cutting fluid's performance in a production environment.

The laboratory tests indicated that a particular generic type of milling fluid would double tool life and a turning fluid would increase tool life by 30%. Performance tests conducted under actual production conditions at the Arsenal confirmed this.

B. The new milling cutting fluid did not eliminate the chipping on the carbide insert.

The chipping may be caused by the long extensions used with the milling cutters which can cause vibrations.

4.5 Cutting Fluid Recycling Conclusions

A. RIA's current production schedule lends itself to a central reprocessing system.

Currently, the Arsenal is operating three shifts 300 days per year. Any downtime due to a machine operator having to perform chip removal or cutting fluid installation is multiplied by a factor of \$42,804/hour x number of machines.

5.0 RECOMMENDATIONS

Based on the Phase I, Phase II and Phase III program findings, the following immediate and long range recommendations are presented as follows.

5.1 Immediate Recommendations

The following is a list of suggested courses of action that have the potential to reduce the Rock Island Arsenal's operating cost without major costs or system changes.

A. Mix the cutting fluids with a positive displacement pump.

Currently, the cutting fluids are mixed with a Venturi type of mixer. This method's accuracy depends on the variation of the water pressure supplied to it. This may be the major reason that many of the observed sumps have too lean of a cutting fluid mixture.

B. Add bacteria controlling agents to problem machine sumps.

It was noted that the main reason for cutting fluid discard at RIA was the hydrogen sulfide (rotten egg) odor which can be attributed to a high population of anerobic bacteria. This level is in the range above 1×10^5 to 1×10^6 bacteria on a plate count. Therefore, adding bacteria controlling agents to the cutting fluid will reduce the growth of bacteria and increase the sump's usable life.

C. Mix the make-up cutting fluid to the dilution ratio that is required for the machine operation in question.

Various machine operations require different dilution ratios for their make-up cutting fluids. The dilution ratios depend on the amount of splashout, the amount of evaporation and/or the amount of dragout of the operation in question. For example, a turning operation is a high dragout operation which is caused by cutting fluid accumulating with the chips. This action removes the diluted cutting fluid mixture from the sump leaving the fluid at the same concentration level. The make-up should be at the recommended concentration level. Grinding produces a high degree of water evaporation from the fluid which increases the concentration of the remaining fluid. This situation calls for a make-up fluid with a lower concentration level which adds more water to the system. This causes the sump concentration level to equalize to the original recommended concentration level.

D. Monitor the concentration levels of all machine sumps.

Currently, the concentration control of the sumps may be improved if accurate methods to determine their concentration can be developed. A refractometer by itself is not an accurate method to determine the concentration of a cutting fluid after it is in use. The refractometer should be coupled with laboratory tests and used as an indicator that the cutting fluid is within a specified concentration range.

Most cutting fluid manufacturers offer a laboratory service as part of their cutting fluid cost. This service could be used to establish refractometer indices for a particular type of machine with a particular maintenance problem performing a manufacturing process. For example, a group of older lathes could have a hydraulic oil leakage

problem. The refractometer index for this group of equipment will be different than if they did not leak hydraulic fluid into the cutting fluid. A refractometer reading should be taken of a sample of the fluid in the machine sump and recorded. Then the same sample should also be sent to the manufacturer's cutting fluid lab for analysis. The actual concentration level of the fluid can then be defined and a calibration factor established for the refractometer readings. Several samples must be taken to develop a refractometer range for this process. When this is determined, accurate make-up cutting fluids can be mixed for this operation. Note: If the cutting fluid ever gets out of the established refractometer range, further lab tests should be made.

Another form of cutting fluid concentration control recommended by some cutting fluid manufacturers is an analytical testing procedure called titration. This procedure measures the exact amount of a critical component of the cutting fluid. This procedure will accurately determine the concentration of the fluid.

Titration cannot be easily performed on all cutting fluids. Each cutting fluid manufacturer being used should be questioned as to how this procedure can best be performed in a manufacturing environment.

E. RIA should institute a machine cleaning program.

Anerobic bacteria is the main reason for cutting fluid sump changes. This form of bacteria will be minimized with an effective machine cleaning program.

F. A study should be made to characterize RIA's material microstructure.

During Phase II's program effort, a definite relationship between micro-structure and process machinability was noted. This relationship should be further investigated by the Arsenal.

5.2 Long Range Recommendations

The long range recommendations will be presented first in a summary form and then each area will be discussed in detail by the individual technology in succeeding sections.

5.2.1 Summary of the Long Range Recommendations

The following is a list of recommendations that will offer major cost benefits to the Rock Island Arsenal.

1. Install a central cutting fluid recycling system in the planned milling area in Building 211.

This will result in a projected \$1,046,034 a year savings and will have a 100% internal rate of return.

2. Install a central cutting fluid recycling system in the production grinding area in Building 220.

After the installation of a central cutting fluid recycling system, a potential \$121,481 a year cost savings will result with a 27% internal rate of return.

3. Use the existing batch recycling system for the crane way area in Building 220.

Even though a potential cost savings of \$523,650 exists for installing a central recycling system in this area, the feasibility is questionable.

4. Install a high lubricity, slight cooling and effective wetting cutting fluid in the milling operations at Shop M (see Table 3.6-1).

This has the potential cost savings of \$141,835 a year in Shop M for 19 numerical control milling machines.

5. Install a medium lubricity, extreme cooling and slight wetting cutting fluid for turning and grinding in Shops M and L (see Table 3.6-1).

An estimated cost savings of \$439,673 may be realized if this is accomplished.

5.2.2 Recommendations for a Cutting Fluid Recycling System

This section will first discuss some of the background required to make a cutting fluid recycling system evaluation. This will be followed by recommendations for the following areas: Shop M craneway area, Shop M new milling area, and production grinding.

5.2.2.1 Background

In general, specifying a cutting fluid recycling system requires taking into account many considerations. First, the exact specifications of the machining area in question must be defined. The elements of these specifications are as follows:

1. The number of machines being recycled.
2. The cutting fluid type required and its specifications.
3. The filtration requirements.
4. The total number of sump gallons used.
5. The average sump life.
6. The size of the largest sump.
7. The layout of the equipment.
8. The fluid flow capabilities of the equipment being used.
9. The number of working hours per year.
10. The manpower required for chip handling.

From this information, the type, size and specifications of a cutting fluid recycling system can be generated. Once the specifications are defined, an evaluation of the various forms of recycling may be initiated. The procedure for this was presented in section 3.7.2 and should be followed in order to develop a complete evaluation. The recommendations that will follow this section are based on the data supplied by RIA personnel and general estimates

supplied by cutting fluid recycling manufacturers. The projected cost savings are also based on these data.

5.2.2.2 Recommendations for Cutting Fluid Recycling Systems at the Rock Island Arsenal

In order to develop recommendations for a cutting fluid recycling method, two major factors must be considered: economic justification and installation feasibility. These factors will be discussed in depth in the following sections.

The current operating practices at RIA dictate that a central cutting fluid system will produce the greatest cost savings. Please refer to Appendix H which compares a central cutting fluid recycling system to batch recycling. RIA is currently operating three shifts per day 300 days per year. This indicates that any reduction in machine downtime will generate a cost savings. The major advantage a central cutting fluid recycling system has over batch recycling is the reduction of chip handling costs. In the craneway area alone, a \$1,305,522 per year savings can be realized with a one-half hour per machine reduction in downtime for chip handling per shift (see Appendix H).

It is recommended, based on long term economic advantages, that three central cutting fluid recycling systems be installed in Shop M. These systems should be installed in the following areas:

1. The craneway area, building 220 (61 machines).
2. The planned milling area to be constructed in building 211 (48 machines).
3. Production grinding (60 machines).

The total cost savings for implementing these systems is \$1,691,165 per year. A cost breakdown and recommended generic type cutting fluid for each area is displayed in Table 5.2-1. From this table it is quite evident that the cost savings generated by implementing a central cutting fluid recycling system outweighs the savings produced by using a particular cutting fluid by a factor of 6. Also, the area that has the greatest individual cost savings is the new milling area to be constructed in building 211. This area should be the first area for implementation.

Securing construction costs and specifications is well beyond the scope of this contract. However, some ballpark cost estimates were obtained. These estimates indicate that the systems required in the craneway and in production grinding can pay for themselves in three years with an internal rate of return of 27%. The system required for the planned milling area in building 211 will pay for itself in one year with an internal rate of return of 100%.

When considering the installation of a central cutting fluid recycling system, cost savings is not the only area of consideration. The entire area of the proposed installation must be studied to determine the feasibility of such an installation. The feasibility study must be conducted with the facility engineering personnel of the plant, the various contractors involved and plant management. TRW has reviewed the feasibility of the recommended central recycling systems with various contractors and the following has been

TABLE 5.2-1

PROJECTED YEARLY COST SAVINGS FOR THE RECOMMENDED CENTRAL CUTTING FLUID RECYCLING
SYSTEM AND GENERIC CUTTING FLUID

Area	Projected Central System Cost Savings	Generic Cutting Fluid Qualities	Cutting Fluid Cost Savings	Total Cost Savings
Craneway Building 220 (61 machines)	\$523,650	High Lubricity Slight Cooling Effective Wetting	\$141,835*	\$665,485
Planned Milling Area Building 211 (48 machines)	\$1,046,034	High Lubricity Slight Cooling Effective Wetting	\$141,835**	\$1,187,869
Production Grinding (60 machines) Building 220	\$121,481	Medium Lubricity Extreme Cooling Slight Wetting	Negligible Compared To Other Areas Using Conser- vative Estim- ing	\$121,481
TOTAL	\$1,691,165		\$283,670	\$1,974,835

*Savings reflects only 19 numerical control milling machines in craneway. The turning cost saving must be given up due to the one fluid restriction.

**It is assumed that the new numerical control milling area will generate at least as much of a cost saving as the existing numerical control mills.

determined. The planned milling area in building 211 is the most feasible installation. This is due to the fact that the manufacturing equipment for this area has not been installed and the proposed layout meets the qualifications for a central system. The installation cost for the central recycling system will be minimized because it can be shared with the machine installation. Production grinding is the second most feasible area for the construction of a central cutting fluid recycling system. The main problem in installing a central system in the grinding area is that an office area is directly below it. The feasibility of troughing for this installation is questionable. However, a network of piping could be used. The only area that has a questionable feasibility is the craneway area in building 220. Many of the machines would have to have their bases removed, be raised up and/or moved. The present machine layout is just not conducive for any form of troughing system. Even though the cost of the necessary alterations may be justified by the future yearly cost savings, RIA management may not want its equipment down for the time period required to make the alterations. Therefore, TRW recommends as a second alternative that a batch recycling system be used in this area.

5.2.3 Central Cutting Fluid Recycling Recommendations for Equipment Specifications

This section will provide recommendations for equipment contained in a central cutting fluid recycling system for machining and grinding at the RIA.

5.2.3.1 Cutting Fluid Recycling Equipment Recommendations for Machining

There are four areas of concern that must be addressed when specifying a cutting fluid recycling system for the machining area at the Arsenal. These are: clarification specifications, method of chip removal, procedure for handling multiple materials, and what happens if the system breaks down.

The first area of concern, cutting fluid recycling system's clarification specifications, has been reviewed by TRW (see Appendix F). Any one of the methods covered in Appendix F may be selected by the Arsenal through its competitive bidding process. However, it is recommended that the following criteria should be met or exceeded:

Tramp Oil - 1% or less.

Cutting Fluid Cleanliness - 30 microns, 20 ppm or less.

Pressure at Nozzle - 25 to 30 psi.

Flow Rate at Nozzle - 5 to 10 gpm.

In order to meet the tramp oil restriction, the addition of a centrifuge may be necessary depending on the type of clarification equipment and cutting fluid selected. This would be connected in a parallel mode of operation because typically a centrifuge operates at a lower flow rate than a central system. This method was used at a TRW facility which used a vacuum type filter and a premium emulsion similar to the Arsenal's Trimsol. A 20 to 30 percent increase in fluid life was reported with the addition of a centrifuge.

The method of chip removal must next be considered. Hinge pan conveyors should be selected over a troughing system. The extra cost of this method is outweighed by three advantages: 1) hinge pan conveyors are able to remove large bundles of chips without clogging; 2) are designed to be mounted above ground which will eliminate the need to hang the system from the basement ceiling as required of a troughing system; and 3) can be easily

relocated if necessary.

The handling of ferrous and nonferrous material at the same time is the third area of concern. This problem will be solved through use of an additional hinge pan conveyor that will handle the other material. The machines will have dual chutes. One chute will go to the 4140 material side while the other will lead to the nonferrous side. If a third type of material is required, a special hopper system will be used that will accommodate this material at the required machine.

The last concern is "What happens if the central system breaks down?" A bathtub type of system could be used utilizing a machine's current sump system. Fresh cutting fluid could constantly be made to circulate through the existing machine sump. Pressure valves would be installed so that, when a loss of input pressure is experienced from the central system, the machine sump's output valve, which normally allows the cutting fluid to return to the central system, would close and divert the fluid to the machine's nozzle. After this occurs, the machine will be operating with its own machine sump.

5.2.3.2 Cutting Fluid Recycling Equipment Recommendations for Grinding

The following three areas will be addressed in order to specify a grinding cutting fluid recycling system for RIA: 1) clarification, 2) swarf removal and 3) what happens if the system breaks down.

As with machining, the cutting fluid recycling system's specifications must be clarified. The following criteria should be met or exceeded:

Tramp Oil - 1% or less.

Cutting Fluid Cleanliness - 15 microns, 15 ppm or less.

Pressure at Nozzle - 25 to 30 psi.

Flow Rate at Nozzle - 30 gpm.

Secondly, grinding swarf removal can be performed using one of two methods: attaching troughs to the basement ceiling or using piping in the production grinding area. Troughing is by far the most reliable method because it can readily be cleaned. However, since offices are currently located in the basement area, piping is recommended because it will not interfere with office personnel.

Lastly it is recommended that the bathtub approach be used as a course of action during breakdown of the central system (see Section 5.2.3.1.). This method will minimize the amount of machine downtime.

5.2.3 Cutting Fluid Recommendations

5.2.3.1 Milling Cutting Fluid Recommendations

The Phase II and III testing and demonstration results indicate that milling at RIA is a lubrication sensitive process, meaning that the greater the lubrication property of the

cutting fluid used the more material a cutting tool will remove prior to failure. Also, the wetting ability of the cutting fluid is important in milling at RIA. This is the capability of the cutting fluid to reach and stay at the chip/tool interface. The cooling ability of a milling cutting fluid should be kept to a minimum. The example fluid used for the demonstration, D. A. Stuart's Dascool 502, contained a special formulation of polar fatty acids and a wetting agent. This combination proved to be an effective cutting fluid for milling. The qualities of this fluid are high lubricity, slight cooling and effective wetting. This generic type fluid should be used in all the milling operations at the Arsenal. A potential cost savings for using this fluid in 19 numerical control milling machines in Shop M is \$141,835.

5.2.3.2 Turning Cutting Fluid Recommendations

During the Phase II testing, it was reported that the turning operations performed at the Arsenal are heat sensitive. This indicates that a cutting fluid must reduce the temperature at the chip/tool interface in order to be effective. Reducing the temperature may be accomplished by two methods: 1) providing lubrication which lowers the frictional force which in turn reduces the heat input being generated and 2) providing cooling to remove the heat from the chip/tool interface. Therefore, two cutting fluid properties, high lubricity, with moderate cooling and slight wetting, or medium lubrication, with extreme cooling and slight wetting, can be used for turning. The high lubricity fluid used in the Phase II testing program was Gulf Oil's Gulfcut HD which contains sulfur as an extreme pressure lubricant. Cincinnati Milacron's Cimcool 400 was the extreme cooling cutting fluid used in the laboratory tests and demonstration conducted at the Arsenal. It is recommended that either generic type of fluid be used in turning at the Arsenal; however, if the extreme cooling type of fluid is selected, it can also be used as a grinding fluid because, in most cases, this type of fluid is a synthetic. Synthetic types of cutting fluids have had the most favorable results in the production grinding department. The potential cost saving for using these generic types of fluids in turning in Shop M and L is \$439,673 per year.

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APPENDIX A

APPENDIX A

An Explanation of the Components of the Economic Model

The basic form of the economic model is as follows:

Yearly Operating Cost = fluid costs + manufacturing costs.

In order to make this a usable model, each component will be broken down into elements and each element will be explained. These components are fluid costs and manufacturing costs.

A.1 Fluid Costs

The cost of using a particular cutting fluid can be divided into three parts: installation cost, maintenance cost and the disposal cost.

Fluid installation cost is the sum of the fluid used cost per gallon, the water used cost per gallon, the labor cost of mixing the fluid and the cost of the necessary additives. Mathematically, the fluid installation cost is:

Fluid Installation Cost = (NF) (GIC) (%C) (FC) + (NF) (GIC) (1-%C) (WC) + (NF) (GIC) (MC) + (NF) (GIC) (%B) (BC) + (NF) (GIC) (%A) (AC)

NF = Number of fluid changes per year

GIC = Gallons of initial change = (Number of machines) (Average sump size)

%C = Percent cutting fluid concentrate used (percent)

FC = Cutting fluid concentrate cost (\$/Gallon)

WC = Water cost (\$/Gallon)

MC = Mixing labor cost (\$/Gallon)

%B = Percent micro-organism control agent used (percent)

BC = Cost of micro-organism control agent (\$/Gallon)

A% = Percent antirust additive (percent)

AC = Antirust additive cost (\$/Gallon)

The maintenance cost is composed of the machine cleaning cost, make-up fluid cost, micro-organism control cost, rust protection control cost, PH control cost, concentration control checking cost and laboratory checking cost. Mathematically this is expressed as follows:

Maintenance Cost =
$$\begin{aligned} & \left[(NF) (\#M) (CT) (LC + EC) + (NF) (\#M) (CCC) \right] + (\#M) (\#S) (WPY) \\ & (MV) (\%M) (FC) + (\#M) (\#S) (WPY) (MV) (1-\%M) (WC) + (\#M) (\#S) \\ & (WPY) (MV) (MC) + (\#M) (\#S) (WPY) (MV) (\%B) (BC) + (\#M) (\#S) (WPY) \\ & (MV) (\%A) (AC) + (APC) + (\#M) (WPY) (0.5) (CC) + (ALC) \end{aligned}$$

NF = Number of fluid changes per year

#M = Number of machines

CT = Cleaning time (hours)

LC = Laborer cost (\$/hour)

EC = Manufacturing equipment cost of being idle (\$/ hour)

CCC = Cleaning chemical cost (\$/pump out)

#S = Number of shifts

WPY = Working days per year

MV = Make-up volume (gallons/shift)

%M = Percent make-up concentrate of fluid

FC = Cutting fluid cost (\$)

WC = Water cost (\$/Gallon)

MC = Mixing labor cost (\$/Gallon)

%B = Percent micro-organism control agent used (percent)

BC = Cost of micro-organism control agent (\$/Gallon)

%A = Percent antirust additive (percent)

AC = Antirust additive cost (\$/Gallon)

APC = Average PH control chemical cost per year (\$)

CC = Cost to check machine concentration (\$/machine)

ALC = Average laboratory chemist checking cost per year (\$)

The disposal cost of a cutting fluid depends on the cutting fluid being used and the method selected by the manufacturing facility to dispose of the fluid. For example, an emulsion type cutting fluid could be disposed of in the manufacturing facility by an acid-alum split. However, this method requires floor space and an individual with some chemical training to carry out this process. The facility may select to pay to haul the fluid out by an outside contractor instead of going through the trouble of doing it in the facility. The expression for yearly disposal cost will be as follows:

Disposal Cost = (NF) (#M) (AS) (DC)

NF = Number of fluid changes

#M = Number of machines

AS = Average sump size (gallons)

DC = Disposal cost (\$/Gallon)

Therefore, the cost of using a cutting fluid is the sum of the installation cost, the maintenance cost and the disposal cost. The complete equation is as follows:

$$\text{Fluid Cost} = \{(\text{NF}) (\text{GIC}) (\%C) (\text{FC}) + (\text{NF}) (\text{GIC}) (1-\%C) (\text{WC}) + (\text{NF}) (\text{GIC}) (\text{MC}) + (\text{NF}) (\text{GIC}) (\%B) (\text{BC}) + (\text{NF}) (\text{GIC}) (\%A) (\text{AC})\} + \left[\{(\text{NF}) (\#M) (\text{CT}) (\text{LC} + \text{EC}) + (\text{NF}) (\#M) (\text{CC})\} + (\#M) (\#S) (\text{WPY}) (\text{MV}) (\%M) (\text{FC}) + (\#M) (\#S) (\text{WPY}) (\text{MV}) (1-\%M) (\text{WC}) + (\#M) (\#S) (\text{WPY}) (\text{MC}) + (\#M) (\#S) (\text{WPY}) (\text{MV}) (\%B) (\text{BC}) + (\#M) (\#S) (\text{WPY}) (\text{MV}) (\%A) (\text{AC}) + (\text{APC}) + (\#M) (\text{WPY}) (0.5) (\text{CC}) + (\text{ALC}) \right] + [(\text{NF}) (\#M) (\text{AS}) (\text{DC})]$$

A.2 Manufacturing Cost

The manufacturing cost of a cutting fluid can be broken down into two parts: tooling costs and miscellaneous costs associated with a particular cutting fluid.

The tooling cost associated with a cutting fluid will be a comparison value which can be either a cost or a savings. This value will be based on tool life studies conducted on the fluids being evaluated. It is assumed that a new fluid will be compared against an existing one. First, a tool life study between the current and new fluid must be completed as described in Section 3.2, and the percent increase or decrease in tooling cost (%TC) must be calculated. The percent expected increase or decrease in tooling cost can then be multiplied times the cost of carbide insert tooling per year, the regrind cost per year and the cost to change inserts per year. An increase in tooling cost will have a positive percent tooling cost value, and a negative percent tooling cost value will indicate a cost savings. This can be expressed mathematically as follows:

$$\text{Tooling Costs} = [(100\%) + (\%TC)] [(ICY) + (\text{RCY}) + (\text{TCI}) \{(\text{HC}) + (\text{EC})\}]$$

%TC = Percent increase or decrease in tooling cost

ICY = Carbide insert cost per year (\$)

RCY = Regrind cost per year (\$)

TCI = Time to change inserts per year (hours)

HC = Hourly cost of a machinist (\$/hour)

EC = Manufacturing equipment cost of being idle

Miscellaneous costs which can reduce the economic benefits a cutting fluid is providing may be divided into two types: cutting fluid manufacturer service and cutting fluid compatibility with the materials being machined.

Cutting fluid manufacturer service is an important factor to consider when selecting a cutting fluid for a manufacturing facility. On occasions a cutting fluid will create problems in the manufacturing facility. These problems may be related to a frozen drum of cutting fluid concentrate, the need for additional bacteria control, unknown contaminants getting into the machine sump and many other unforeseen problems. When such problems exist, production may be stopped until the cutting fluid manufacturer's technical service person can come out to the operating facility and make recommendations. The amount of time it takes for the manufacturer to send a service representative

to analyze the facility's problem is a very important consideration. Also, the quality of the vendor laboratory facilities and the practical experience of the vendor laboratory personnel are very important. These factors all combine together in a synergistic effect which determines the amount of time required to solve the manufacturing facility's cutting fluid problem and once again initiate production.

Cutting fluid compatibility with the materials being machined is very important. A cutting fluid may provide an increase in tool life for ferrous material machining, but if it is not compatible with the non-ferrous materials being machined this may offset any initial cost savings. Tests must be performed to insure cutting fluid compatibility with all materials being manufactured. However, sometimes a cutting fluid will provide such a ferrous machining benefit that an added operation or cleanup cost for occasional non-ferrous parts can be tolerated. This is why a compatibility miscellaneous cost is being considered as part of this economic model.

The miscellaneous cost may be expressed mathematically as follows:

$$\text{Miscellaneous Costs} = (\#HM) \left[(HC) + (EC) \right] + (CIC) - \left[(HC) + (EC) \right] (PRM) (CHM)$$

#HM = Number of hours a cutting fluid manufacturer will allow production to be down before solving a cutting fluid problem (hours)

HC = Hourly cost of a machinist (\$/hour)

EC = Manufacturing equipment cost of being idle (\$/hour)

CIC = The additional cost incurred due to a material incompatibility with a cutting fluid.

PRM = The percent of reduction of machining time due to the ability of a new cutting fluid to increase the feed and speed rate over the old fluid.

CMH = The current yearly machine hours for the operation in which the new fluid will be used.

A.3 Mathematical expression for the complete economic model

- (1) Yearly Fluid Operating Cost = fluid costs + manufacturing costs.
- (2) Yearly Fluid Operating Cost = fluid installation cost + maintenance cost + disposal cost + tooling costs + miscellaneous costs.
- (3) Yearly Fluid Operating Cost = fluid used cost per gallon + water used cost per gallon + labor cost of mixing the fluid + cost of additives + machine cleaning cost + make-up fluid cost + micro-organism control cost + rust protection control cost + PH control cost + concentration control checking cost + laboratory checking cost + disposal cost + tooling costs + cutting fluid manufacturer service + cutting fluid compatibility costs - increase in machining parameter savings.
- (4)
$$\begin{aligned} YFOC = & (NF) (GIC) (\%C) (FC) \\ & + (NF) (GIC) (1-\%C) (WC) + (NF) (GIC) (MC) \\ & + (NF) (GIC) (\%B) (BC) + (NF) (GIC) (\%A) (AC) \\ & + [(NF) (\#M) (CT) (LC + EC) + (NF) (\#M) (CCC)] \\ & + (\#M) (\#S) (WPY) (MV) (\%M) (FC) \\ & + (\#M) (\#S) (WPY) (MV) (1-\%M) (WC) + (\#M) (\#S) (WPY) (MV) (MC) \\ & + (\#M) (\#S) (WPY) (MV) (\%B) (BC) \end{aligned}$$

$$\begin{aligned}
& + (\#M) (\#S) (WPY) (MV) (\%A) (AC) + (APC) + (\#M) (WPY) (0.5) (CC) + (ALC) \\
& + (NF) (\#M) (AS) (DC) \\
& + [(100\%) + (\%TC)] [(ICY) + (RCY) + (TCD) \{ (HC) + (EC) \}] \\
& + (\#HM) [(HC) + (EC)] + (CIC) - [(HC) + (EC)] (PRM) (CMH)
\end{aligned}$$

YFOC = Yearly fluid operating cost.

NF = Number of fluid changes per year.

GIC = Gallons of initial change = (number of machines) (average sump size).

%C = Percent cutting fluid concentrate used (percent).

FC = Cutting fluid concentrate cost (%/Gallon)

WC = Water cost (\$/Gallon)

MC = Mixing labor cost (\$/Gallon)

%B = Percent micro-organism control agent (percent)

BC = Cost of micro-organism control agent (\$/Gallon)

%A = Percent antirust additive (percent)

AC = Antirust additive cost (\$/Gallon)

#M = Number of machines

CT = Cleaning time (hours)

LC = Labor cost (\$/hour)

EC = Manufacturing equipment cost of being idle (\$/hour)

CCC = Cleaning chemical cost (\$/pumpout)

#S = Number of shifts

WPY = Working days per year

MV = Make-up volume (gallons/shift)

%M = Percent make-up concentrate of fluid

FC = Cutting fluid cost (\$)

WC = Water cost (\$/gallon)

APC = Average PH control chemical cost per year (\$)

CC = Cost to check machine concentration (\$/machine)

ALC = Average laboratory chemist checking cost per year (\$)

AS = Average sump size (gallons)

DC = Disposal cost (\$/gallons)

%TC = Percent increase or decrease in tooling cost

ICY = Carbide insert cost per year (\$)

RCY = Regrind cost per year (\$)

TCI = Time to change inserts per year (hours)

HC = Hourly cost of a machinist (\$/hour)

EC = Manufacturing equipment cost of being idle

#HM = Number of hours a cutting fluid manufacturer will allow production to be down before solving a cutting fluid problem

CIC = The additional cost incurred due to a material compatibility

PRM = The percent reduction of machining time due to the ability of a new cutting fluid to increase the feed and speed rate over the old fluid.

CMH = The current yearly machine hours for the operation in which the new fluid will be used.

APPENDIX B

APPENDIX B

An Example of How The Economic Model Will Work

This example will compare Master Chemical's Trimsol to D. A. Stuart Oil Company's Dascool 502 for numerical control milling at RIA. In order to make this example more understandable, the economic model will be divided into its elements: fluid installation cost, maintenance cost, disposal cost, tooling costs and miscellaneous costs.

B.1 Fluid Installation Cost

$$\text{Fluid Installation Cost} = (\text{NF}) (\text{GIC}) (\%C) (\text{FC}) + (\text{NF}) (\text{GIC}) (1-\%C) (\text{WC}) + (\text{NF}) (\text{GIC}) (\text{MC}) + (\text{NF}) (\text{GIC}) (\%B) (\text{BC}) + (\text{NF}) (\text{GIC}) (\%A) (\text{AC})$$

NF: NF is the number of times per year a particular cutting fluid will have to be changed. When possible this value should be based on past production data. Master Chemical's Trimsol will usually last one month prior to being pumped out. The number of fluid changes per year for Trimsol will be twelve. When production data is not available, a best estimate must be made. Typically, a synthetic fluid will last two to three times longer than an emulsion. It will be conservatively assumed that the number of fluid changes for D. A. Stuart's Dascool 502 will be six.

GIC: GIC is the number of gallons of the initial charge of cutting fluid. This can be calculated by multiplying the number of machines (19) by the average sump size (50 gallons). The initial charge will be 950 gallons.

%C: %C is the percent concentrate recommended by the cutting fluid manufacturer. For both Dascool 502 and Trimsol, we will use a 20:1 dilution ratio or 4.76%.

FC: FC is the cutting fluid concentrate cost. Trimsol's cost is \$7.85 per gallon and Dascool 502 is \$7.51 per gallon.

WC: For this example the water cost (WC) will be zero because deionized water will not be used.

MC: MC is the cost incurred when the fluid is mixed by a laborer. As of March 1982 the Arsenal was mixing its fluid with a Venturi type mixer into a 55 gallon drum mounted on a portable cart. From past experience it takes 15 minutes to fill the drum with mixed cutting fluid and wheel it over to a machine. MC can be calculated as follows:

$$\text{MC} = (15 \text{ minutes}) / (60 \text{ minutes/hour}) (\$31/\text{hour, labor and overhead cost}) / 50 \text{ gallons} = \$0.155/\text{gallon}.$$

%B,BC: %B is the percent of micro-organism control concentrate that must be added to a cutting fluid in order to control the bacteria level in the machine sump. BC is the cost of the micro-organism control used. Both Trimsol and Dascool 502 are supplied by the manufacturer with micro-organism control agents. Therefore, no additional costs will be incurred and the values for BC and %B will be zero.

%A,AC: %A is the percent of antirust additive that has to be added to the cutting fluid sump. AC is the cost of the antirust additive. Since both cutting fluid manufacturers supply antirust additives in the cutting fluid, no additional costs will be incurred. The values for AC and %A will be zero.

The yearly fluid installation cost can now be calculated for Trimsol and Dascool 502.

Fluid Installation Cost (Trimsol) = (12) (950 gallons) (0.0476) (\$7.85/gallon) + 0 + (12) (950 gallons) (\$0.155/gallon) + 0 + 0.

Fluid Installation Cost (Trimsol) = \$6,028.

Fluid Installation Cost (Dascool 502) = (6) (950 gallon) (0.0476) (\$7.51/gallon) + 0 + (6) (950 gallon) (\$0.155/gallon) + 0 + 0.

Fluid Installation Cost (Dascool 502) = \$2,921.

B.2 Maintenance Cost

Maintenance Cost = $[(NF) (\#M) (CT) (LC + EC) + (NF) (\#M) (CCC)] + (\#M) (\#S) (WPY) (MV) (\%M) (FC) + (\#M) (\#S) (WPY) (MV) (1-\%M) (WC) + (\#M) (\#S) (WPY) (MV) (MC) + (\#M) (\#S) (WPY) (MV) (\%B) (BC) + (\#M) (\#S) (WPY) (MV) (\%A) (AC) + (APC) + (\#M) (WPY) (0.5) (CC) + (ALC)$

NF: NF is the number of fluid changes per year. These are the same values as calculated for the fluid installation cost: 12 for Trimsol and 6 for Dascool 502.

#M: #M is the number of machines that are being used. There are 19 milling machines in the crane way area.

CT: CT is the amount of time necessary to clean out a machine. The amount of time necessary to clean out a numerical control milling machine at RIA is 1.5 hours.

LC: LC is the labor cost per hour to clean out a machine. This cost is \$31.00 per hour including overhead.

EC: EC is the cost of having a piece of equipment idle. The cost of having a numerical control milling machine idle is not applicable at RIA.

CCC: CCC is the cleaning chemical cost per pumpout. This may be calculated by the following formula:

CCC = (sump size) (0.66) (% machine cleaning concentrate) (cost of machine cleaning concentrate).

CCC = (50 gallon sump) (0.66) (0.05) (\$6.43/gallon).

CCC = \$10.61/pumpout.

#S: #S is the number of shifts the manufacturing facility works. The numerical control milling area works 3 shifts.

WPY: WPY is the number of working days the manufacturing facility works per year. On the average, the numerical control milling area works 300 days per year.

MV: MV is the make-up volume required per shift for a particular cutting fluid. Trimsol requires 10 gallons a shift of make-up fluid and Dascool 502 requires 20 gallons.

%M: %M is the percent make-up cutting fluid concentrate required for a particular cutting fluid. Trimsol requires a 4.76 makeup percentage (20:1) and Dascool 502 requires 3.23 percent make-up (30:1).

FC: FC is the cutting fluid cost. Trimisol's cost is \$7.85 per gallon and Dascool 502's cost is \$7.51 per gallon.

WC: WC is the water cost per gallon. Since deionized water is not being used, the water cost will be zero.

MC: MC is the cost incurred when the cutting fluid is mixed by a laborer. This value is calculated the same way as in fluid installation cost and is \$0.155 per gallon.

%B,BC: %B is the percent of micro-organism control concentrate that must be added to a cutting fluid in order to control the bacteria level in the machine sump. BC is the cost of the micro-organism control agent used. As in the fluid installation cost these values will be zero.

%A,AC: %A is the percentage of antirust additive that must be added to a cutting fluid sump. AC is the cost of the cutting fluid additive. As in the fluid installation cost these values are zero.

APC: APC is the average PH control chemical cost per year. In general, small individual machine sumps do not require PH control. This is because the daily make-up volume will usually take care of any PH variations. Therefore, the PH control chemical cost per year will be zero for this example.

CC: CC is the cost to check a machine sump's concentration. Assuming a refractometer is used to check a machine sump's concentration, it should take 4 minutes to make a concentration check. The labor rate for a concentration checker is \$31.00 per hour including overhead. Using the following formula, the value for CC may be calculated.

$$CC = (\text{time for concentration check})(1 \text{ hour}/60 \text{ minutes})(\text{labor cost}/\text{hour}).$$

$$CC = (4 \text{ minutes}/\text{machine})(1 \text{ hour}/60 \text{ minutes}) (\$31.00/\text{hour}).$$

$$CC = \$2.06/\text{machine}.$$

ALC: ALC is the average laboratory checking cost per year. It is assumed that 8 hours of laboratory checking procedures will be required per week. Some of the procedures required are fluid titration checks and bacteria level checks. The rate paid to a laboratory worker including overhead is \$32.25/hour. The ALC may be calculated using the following formula:

$$ALC = (\text{hours per week required}) (52 \text{ weeks}/\text{year}) (\text{hourly rate}).$$

$$ALC = (8 \text{ hours}) (52 \text{ weeks}/\text{year}) (\$32.25/\text{hour}).$$

$$ALC = \$13,416.$$

The yearly maintenance cost can now be calculated for Trimisol and Dascool 502.

$$MC (\text{Trimisol}) = [(12) (19) (1.5 \text{ hour}) (\$31.00/\text{hour} + \$xx.xx/\text{hour}) + (12) (19) (\$10.61)] + (19) (3) (300) (10 \text{ gallons}) (0.0476) (\$7.85/\text{gallon}) + 0 + (19) (3) (300) (10 \text{ gallons}) (\$0.155/\text{gallon}) + 0 + 0 + 0 + (19) (300) (0.5) (\$2.06) + \$13,416.$$

$$MC (\text{Trimisol}) = \$122,709.$$

Note: xx.xx indicates that this item is not applicable to RIA.

MC (Dascool 502) = $[(6)(19)(1.5 \text{ hour})(\$31.00/\text{hour} + \$xx.xx/\text{hour}) + (6)(19)(\$10.61)] + (19)(3)(300)(20 \text{ gallons})(0.0323)(\$7.51/\text{gallon}) + 0 + (19)(3)(300)(20 \text{ gallons})(\$0.155/\text{gallon}) + 0 + 0 + 0 + (19)(300)(0.5)(\$2.06) + \$13,416.$

MC (Dascool 502) = \$161,768.

B.3 Disposal Cost

Disposal Cost = (NF) (#M) (AS) (DC).

NF: NF is the number of fluid changes per year. This value is calculated the same way as in fluid installation cost. Trimisol will have 12 fluid changes per year and Dascool 502 will have 6.

#M: #M is the number of machines. There are 19 numerical control milling machines in the crane way area.

AS: AS is the average sump size of the equipment being used. The average sump size of the numerical control milling equipment is 50 gallons.

DC: DC is the disposal cost of removing the spent cutting fluid from the operating facility. Currently, the Arsenal removes its fluid by having an outside contractor haul it away at the cost of \$0.14 per gallon. The yearly cost can now be calculated for Trimisol and Dascool 502.

DC (Trimisol) = $(12)(19)(50 \text{ gallons})(\$0.14/\text{gallon}).$

DC (Trimisol) = \$1,596.

DC (Dascool 502) = $(6)(19)(50 \text{ gallons})(\$0.14/\text{gallon}).$

DC (Dascool 502) = \$798.

B.4 Tooling Costs

Tooling Costs = $[(100\% + \%TC)] [(ICY) + (RCY) + (TCI) [(HC) + (EC)]]$

%TC: %TC is the percent increase or decrease in tooling cost. The laboratory tests and the RIA demonstration both showed that tool life will be doubled using Dascool 502. Thus the %TC for Dascool 502 is a -50%. Trimisol being the baseline fluid will not have a change in tool life and will have a %TC value of zero. The value of zero for %TC will give the baseline fluid 100% of the tooling cost. Using this mathematical logic, the value for the tooling cost will show how much of an increase or decrease in tooling cost exists by using a new fluid.

ICY: ICY is the carbide tooling cost per year associated with the studied machining operation. It has been estimated that the carbide insert cost for the numerical control area is \$111,002 per year. It will be assumed that half of that value is used in numerical control milling or \$55,501.

RCY: RCY is the yearly regrind cost. The yearly regrind cost for the Arsenal is 3 million dollars per year. The exact cost associated with the regrinds for the numerical control milling operation is very difficult to determine. It will be conservatively estimated that 10% of the regrind costs are for numerical control milling or \$300,000.

Note: xx.xx indicates that this item is not applicable to RIA.

TCI: TCI is the time required to change inserts. For the numerical control milling operations, the time required to change inserts may be considered as zero. This is because most of the carbide insert tool changes can be made internal to the cycle of another operation.

HC: HC is the hourly cost of a machinist. The hourly cost of a machinist at the Arsenal is \$47.56 per hour.

EC: EC is the manufacturing equipment cost of being idle. The numerical control milling equipment cost of being idle is not applicable at RIA.

The yearly tooling costs can now be calculated.

$$YTC (\text{Trimsol}) = [(100\%) + (0\%)] [(\$55,501) + (\$300,000) + (0) \{(\$47.56/\text{hour}) + (xx.xx/\text{hr})\}]$$

$$YTC (\text{Trimsol}) = \$355,501.$$

$$YTC (\text{Dascool 502}) = [(100\%) + (-50\%)] [(\$55,501) + (\$300,000) + (0) \{(47.56/\text{hour}) + (xx.xx/\text{hr})\}].$$

$$YTC (\text{Dascool 502}) = \$177,751$$

B.5 Miscellaneous Costs

$$\text{Miscellaneous Costs} = (\#HM) [(HC) + (EC)] + (CIC) - [(HC) + (EC)] (PRM) (CMH).$$

#HM: #HM is the number of hours a cutting fluid manufacturer will allow production to be down before solving a cutting fluid problem. Trimsol has had a very good record at the Arsenal and will be given a #HM of zero. However, Dascool 502 has no experience at the Arsenal. It will be estimated that the #HM for Dascool 502 will be 16 hours.

HC: HC is the hourly cost of a machinist. The hourly cost of a machinist at the Arsenal is \$47.56 per hour.

EC: EC is the manufacturing equipment cost of being idle. The numerical control milling equipment cost of being idle is not applicable at RIA.

CIC: CIC is the additional cost incurred due to material incompatibility with a cutting fluid. The CIC value for both Trimsol and Dascool 502 is zero. Both fluids are compatible with all the materials machined at the Arsenal.

PRM: PRM is the percent reduction of machining time due to the ability of a new cutting fluid to increase the feed and speed rate over the old fluid. The PRM value for this comparison will be zero because no attempt was made to increase feeds or speeds.

CMH: CMH is the current yearly machine hours for the operation in which the new fluid will be used. The CMH value will be zero for this comparison because no attempt was made to increase the feed or speed rates.

The miscellaneous costs can now be calculated for Trimsol and Dascool 502.

$$MC (\text{Trimsol}) = (0) (\$47.56/\text{hour} + xx.xx/\text{hour}) + 0 - [(\$47.56/\text{hour}) + (xx.xx/\text{hour})] (0) (0)$$

$$MC (\text{Trimsol}) = 0$$

Note: xx.xx indicates that this item is not applicable to RIA.

Note: The negative value for %TC indicates a cost savings.

$$MC (\text{Dascool } 502) = (16 \text{ hours}) (\$47.56/\text{hour} + xx.xx/\text{hour}) + 0 - [(\$47.56/\text{hour} + (xx.xx/\text{hour})) (0) (0)]$$

$$MC (\text{Dascool } 502) = \$761$$

B.6 Summation of the Economic Model's Elemental Costs

This section will total all of the individual elements of the Economic Model which will project the yearly operating cost of one cutting fluid compared to another.

Yearly Fluid Operating Costs = Fluid installation cost + maintenance cost + disposal cost + tooling cost or benefit + miscellaneous costs.

The Yearly Fluid Operating Cost (YFOC) will now be calculated for Trimsol and Dascool 502.

$$YFOC (\text{Trimsol}) = \$6,028 + \$122,709 + \$1,596 + \$355,501 + 0$$

$$YFOC (\text{Trimsol}) = \$485,834$$

$$YFOC (\text{Dascool } 502) = \$2,921 + \$161,768 + \$798 + \$177,751 + \$761$$

$$YFOC (\text{Dascool } 502) = \$343,999$$

The Economic Model indicates that Dascool 502 will generate a \$141,835 per year cost savings over using Trimsol.

APPENDIX C

APPENDIX C

ECONOMIC COMPARISON BETWEEN MASTER CHEMICAL'S TRIMSOL AND CINCINNATI MILACRON'S CIMCOOL 400 FOR NUMERICAL CONTROL TURNING

This appendix will show the economic advantage of using the example fluid, Cimcool 400, over Trimsol. This exercise will follow the same format as in Appendix B using the economic model.

C.1 Fluid Installation Cost

Fluid Installation Cost = (NF) (GIC) (%C) (FC) + (NF) (GIC) (1-%C) (WC) + (NF) (GIC) (MC) + (NF) (GIC) (%B) (BC) + (NF) (GIC) (%A) (AC).

NF:

NF is the number of times per year a particular cutting fluid will have to be changed. Master Chemical's past production record is one month between pumpouts. It will conservatively be assumed that Cimcool 400 will last two months between pumpouts.

GIC:

GIC is the number of gallons of the initial charge of cutting fluid. This can be calculated by multiplying the number of machines (19) by the average sump size (50 gallons). The initial charge will be 950 gallons.

%C:

%C is the percent concentrate recommended by the cutting fluid manufacturer. For both Cimcool 400 and Trimsol, a 20:1 dilution ratio or 4.76% will be used.

FC:

FC is the cutting fluid concentrate cost. Trimsol's cost is \$7.85 per gallon and Cimcool 400 is \$8.10 per gallon.

WC:

WC is the cost for water. For this comparison the water cost will be zero because deionized water will not be used.

MC:

MC is the cost incurred when the fluid is mixed by a laborer. As of March 1982, the Arsenal was mixing its fluid with a Venturi type mixer into a 55 gallon drum mounted on a portable cart. From past experience, it takes 15 minutes to fill the drum with mixed cutting fluid and wheel it over to a machine. MC can be calculated as follows:

MC = (15 minutes)/(60 minutes/hour) (\$31/hour, labor and overhead cost)/50 gallons = \$0.155/gallon.

%B,BC:

%B is the percent of micro-organism control concentrate that must be added to a cutting fluid in order to control the bacteria level in the machine sump. BC is the cost of the micro-organism control used. Both Trimsol and Cimcool 400 are supplied by the manufacturer with micro-organism control agents. Therefore, no additional costs will be incurred and the values for BC and %B will be zero.

%A, AC:

%A is the percent of antirust additive that has to be added to the cutting fluid sump. AC is the cost of the antirust additive. Since both cutting fluid manufacturers supply antirust additives in the cutting fluid, no additional costs will be incurred. The values for AC and %A will be zero.

The yearly fluid installation cost can now be calculated for Trimsol and Cimcool 400.

Fluid Installation Cost (Trimsol) = (12) (950 gallons) (0.0476) (\$7.85/gallon) + 0 + (12) (950 gallons) (\$0.155/gallon) + 0 + 0.

Fluid Installation Cost (Trimsol) = \$6,028.

Fluid Installation Cost (Cimcool 400) = (6) (950 gallons) (0.0476) (\$8.10/gallon) + 0 + (6) (950 gallons) (\$0.155/gallon) + 0 + 0.

Fluid Installation Cost (Cimcool 400) = \$3,081.

C.2 Maintenance Cost

Fluid Maintenance Cost = $\left[(NF) (\#M) (CT) (LC + EC) + (NF) (\#M) (CCC) \right] + (\#M) (\#S) (WPY) (MV) (\%M) (FC) + (\#M) (\#S) (WPY) (MV) (1 - \%M) (WC) + (\#M) (\#S) (WPY) (MV) (MC) + (\#M) (\#S) (WPY) (MV) (\%B) (BC) + (\#M) (\#S) (WPY) (MV) (\%A) (AC) + (APC) + (\#M) (WPY) (0.5) (CC) + (ALC).$

NF:

NF is the number of fluid changes per year. These are the same values as for the fluid installation cost: 12 for Trimsol and 6 for Cimcool 400.

#M:

#M is the number of machines that are being used. There are 19 numerical control turning machines in the crane way area.

CT:

CT is the amount of time necessary to clean out a machine. The amount of time necessary to clean out a numerical control turning machine at RIA is 1.25 hours.

LC:

LC is the labor cost per hour to clean out a machine. This cost is \$31.00/hour including overhead.

EC:

EC is the cost of having a piece of equipment idle. The cost of having a numerical control turning machine idle is not applicable at RIA.

CCC:

CCC is the cleaning chemical cost per pumpout. This may be calculated by the following formula:

$CCC = (\text{sump size}) (0.66) (\% \text{ machine cleaning concentrate}) (\text{cost of machine cleaning concentrate}).$

$CCC = (50 \text{ gallon sump}) (0.66) (0.05) (\$6.43/\text{Gallon}).$

CCC = \$10.61/pumpout.

#S:

#S is the number of shifts the manufacturing facility works. The numerical control turning area works three shifts.

WPY:

WPY is the number of working days the manufacturing facility works per year. On the average, the numerical control turning area works 300 days per year.

MV:

MV is the make-up volume required per shift for a particular cutting fluid. Trimsol requires 10 gallons per shift of make-up fluid and Cimcool 400 requires 20 gallons.

%M:

%M is the percent make-up cutting fluid concentrate required for a particular cutting fluid. Trimsol requires a 4.76 make-up percentage (20:1) and Cimcool 400 requires 2.78 percent make-up (35:1).

FC:

FC is the cutting fluid cost. Trimsol's cost is \$7.85 per gallon and Cimcool 400 cost is \$8.10 per gallon.

WC:

WC is the water cost per gallon. Since deionized water is not being used, the water cost will be zero.

MC:

MC is the cost incurred when the cutting fluid is mixed by a laborer. This value is calculated the same way as in fluid installation cost and is \$0.155/gallon.

%B, BC:

%B is the percent of micro-organism control concentrate that must be added to a cutting fluid in order to control the bacteria level in the machine sump. BC is the cost of the micro-organism control agent used. As in the fluid installation cost, these values will be zero.

%A, AC:

%A is the percentage of antirust additive that must be added to a cutting fluid sump. AC is the cost of the cutting fluid additive. As in the fluid installation cost, these values are zero.

APC:

APC is the average PH control chemical cost per year. In general, small individual machine sumps do not require PH control. This is because the daily make-up volume will usually take care of any PH variations. Therefore, the PH control chemical cost per year will be zero for this comparison.

CC:

CC is the cost to check a machine sump's concentration. Assuming a refractometer is used to check a machine sump's concentration for Trimsol, it should take 4 minutes to make a concentration check. The labor rate for a concentration checker is \$31.00 per hour. Using the following formula, the value for CC may be calculated.

CC = (time for concentration check) (1 hour/60 minutes) (labor cost/hour).

CC (Trimsol) = (4 minutes/machine) (1 hour/60 minutes) (\$31.00/hour).

CC (Trimsol) = \$2.06/machine.

Cimcool 400 requires a titration in order to check its concentration. The titration should take 7 minutes.

CC (Cimcool 400) = \$3.62/machine.

ALC:

ALC is the average laboratory checking cost per year. It is assumed that 8 hours of laboratory checking procedures will be required per week. Some of the procedures required are fluid titration checks and bacteria level checks. The hourly rate paid to a laboratory worker including overhead is \$32.25/hour. The ALC may be calculated using the following formula:

ALC = (hours per week required) (52 weeks/year) (hourly rate).

ALC = (8 hours) (52 weeks/year) (\$32.25/hour).

ALC = \$13,416.

The yearly fluid maintenance cost can now be calculated for Trimsol and Cimcool 400.

MC (Trimsol) = [(12) (19) (1.25 hours) (\$31.00/hour + \$xx.xx/hour) + (12) (19) (\$10.61)] + (19) (3) (300) (10 gallons) (0.0476) (\$7.85/gallon) + 0 + (19) (3) (300) (10 gallons) (\$0.155/gallon) + 0 + 0 + 0 + (19) (300) (0.5) (\$2.06) + \$13,416.

MC (Trimsol) = \$120,942.

MC (Cimcool 400) = [(6) (19) (1.25 hours) (\$31.00/hour + \$xx.xx/hour) + (6) (19) (\$10.61)] + (19) (3) (300) (20 gallons) (0.0278) (\$8.10/gallon) + 0 + (19) (3) (300) (20 gallons) (\$0.155/gallon) + 0 + 0 + 0 + (19) (300) (0.5) (\$3.62) + \$13,416.

MC (Cimcool 400) = \$159,382.

C.3 Disposal Cost

Disposal Cost = (NF) (#M) (AS) (DC).

NF:

NF is the number of fluid changes per year. This is the same as in the fluid installation cost. Trimsol will have 12 fluid changes per year and Cimcool 400 will have 6.

#M:

#M is the number of machines. There are 19 numerical control turning machines in the crane way area.

Note: xx.xx indicates that this item is not applicable to RIA.

AS:

AS is the average sump size of the equipment being used. The average sump size of the numerical control turning equipment is 50 gallons.

DC:

DC is the disposal cost of removing the spent cutting fluid from the operating facility. Currently, the Arsenal removes its fluid by having an outside contractor haul it away at the cost of \$0.14/gallon. The yearly disposal cost can now be calculated for Trimsol and Cimcool 400.

DC (Trimsol) = (12) (19) (50 gallons) (\$0.14/gallon).

DC (Trimsol) = \$1,596.

DC (Cimcool 400) = \$798.

C.4 Tooling Costs

Tooling Costs = $[100\% + \%TC] [(ICY) + (RCY) + (TCI) \{ (HC) + (EC) \}]$.

%TC:

%TC is the percent increase or decrease in tooling cost. The %TC for Cimcool 400 is a -40%. Trimsol being the baseline fluid will not have a change in tool life and will have a %TC value of zero. The value of zero for %TC will give the baseline fluid 100% of the tooling cost. Using this mathematical logic, the value for the tooling cost will show how much of an increase or decrease in tooling cost exists by using a new fluid.

ICY:

ICY is the carbide tooling cost per year associated with the studied machining operation. It has been estimated that the carbide insert cost for the numerical control area is \$117,002 per year. We will assume that half of that value is used in numerical control turning or \$55,501.

RCY:

RCY is the yearly regrind cost. All of the numerical control turning operations use carbide inserts. For this reason, no regrinding will be necessary.

TCI:

TCI is the time required to change inserts. For the numerical control turning operations, the time required to change inserts will be conservatively estimated as 15 minutes per shift. The time to change inserts per year is 4,275 hours.

HC:

HC is the hourly cost of a machinist. The hourly cost of a machinist at the Arsenal is \$47.56/hour.

EC:

EC is the manufacturing equipment cost of being idle. The numerical control turning equipment cost of being idle is not applicable at RIA.

The yearly tooling cost can now be calculated.

$YTC \text{ (Trimsol)} = [(100\%) + (0\%)] [(\$55,501) + (0) + (4,275 \text{ hours}) (\$47.56/\text{hour}) + (\$xx.xx/\text{hour})]$.

Note: xx.xx indicates that this item is not applicable to RIA.

YTC (Trimsol) = \$258,820.

YTC (Cimcool 400) = $[100\% + (-40\%)]$ (\$55,501) + (0) + (4,275 hours) (\$47.56/hour) + (\$xx.xx/hour)

YTC (Cimcool 400) = \$155,292.

C.5 Miscellaneous Costs

Miscellaneous Costs = (#HM) $[(HC) + (EC)]$ + (CIC) - $[(HC) + (EC)]$ (PRM) (CHM).

#HM:

#HM is the number of hours a cutting fluid manufacturer will allow production to be down before solving a cutting fluid problem. Trimsol has had a very good record at the Arsenal and will be given a #HM of zero. However, Cimcool 400 has no experience at the Arsenal. It will be estimated that the #HM for Cimcool 400 will be 16 hours.

HC:

HC is the hourly cost of a machinist. The hourly cost of a machinist at the Arsenal is \$47.56 per hour.

EC:

EC is the manufacturing equipment cost of being idle. The numerical control turning equipment cost of being idle is not applicable at RIA.

CIC:

CIC is the additional cost incurred due to material incompatibility with a cutting fluid. The CIC value for Trimsol is zero. However, Cimcool 400 is not compatible with aluminum. It will be assumed that two aluminum jobs are machined each month. The cost to clean out a sump which has the Cimcool 400 in it, replace it with an aluminum compatible cutting fluid, clean out the sump again and refill it with Cimcool 400 will cost \$267. The yearly CIC cost will be \$6,408.

PRM:

PRM is the percent reduction of machining time due to the ability of a new cutting fluid to increase the feed and speed rate over the old fluid. The PRM value for this comparison will be zero because no attempts were made to increase feed or speeds.

CMH:

CMH is the current yearly machine hours for the operation in which the new fluid will be used. The CMH value will be zero for this comparison, because no attempts were made to increase the feed or speed rates.

The Yearly Fluid Miscellaneous Costs can now be calculated.

MC (Trimsol) = (0) (\$47.56/hour) + (xx.xx/hour) + 0 - $[(47.56/\text{hour}) + (\text{xx.xx}/\text{hour}) (0) (0)]$.

MC (Trimsol) = 0.

MC (Cimcool 400) = (16 hours) $[(\$47.56/\text{hour}) + (\text{xx.xx}/\text{hour})]$ + \$6,408/year - $[(\$47.56/\text{hour}) + (\text{xx.xx}/\text{hour})] (0) (0)$.

Note: xx.xx indicates that this item is not applicable to RIA.

MC (Cimcool 400) = 7,169.

C.6 Summation of the Elemental Costs

This section will total all of the individual cost elements which will project the yearly operating cost of one cutting fluid compared to another.

Yearly Fluid Operating Costs = fluid installation cost + maintenance cost + disposal cost + tooling cost or benefit + miscellaneous cost.

The Yearly Fluid Operating Cost (YFOC) will now be calculated for Trimsol and Cimcool 400.

YFOC (Trimsol) = \$6,028 + \$120,942 + \$1,596 + \$258,820.

YFOC (Trimsol) = \$387,386.

YFOC (Cimcool 400) = \$3,081 + \$159,382 + \$798 + \$155,292 + \$7,169.

YFOC (Cimcool 400) = \$325,722.

This comparison indicates that Cimcool 400 will generate a \$61,664 per year cost savings over using Trimsol.

APPENDIX D

APPENDIX D

ECONOMIC COMPARISON BETWEEN MASTER CHEMICAL'S TRIMSOL AND CINCINNATI MILACRON'S CIMCOOL 400 FOR SHOP L

This appendix will show the economic advantage of using the example fluid, Cimcool 400, over Trimsol. This exercise will follow the same format as in Appendix B using the economic model.

D.1 Fluid Installation Cost

Fluid Installation Cost = (NF) (GIC) (%C) (FC) + (NF) (GIC) (1-%C) (WC) + (NF) (GIC) (MC) + (NF) (GIC) (%B) (BC) + (NF) (GIC) (%A) (AC).

NF:

NF is the number of times per year a particular cutting fluid will have to be changed. Master Chemical's past production record is one month between pumpouts. It will conservatively be assumed that Cimcool 400 will last two months between pumpouts.

GIC:

GIC is the number of gallons of the initial charge of cutting fluid. This can be calculated by multiplying the number of machines (172) by the average sump size (30 gallons). The initial charge will be 5,160 gallons.

%C:

%C is the percent concentrate recommended by the cutting fluid manufacturer. For both Cimcool 400 and Trimsol, a 20:1 dilution ratio or 4.76% will be used.

FC:

FC is the cutting fluid concentrate cost. Trimsol's cost is \$7.85 per gallon and Cimcool 400 is \$8.10 per gallon.

WC:

WC is the cost for water. For this comparison the water cost will be zero because deionized water will not be used.

MC:

MC is the cost incurred when the fluid is mixed by a laborer. As of March 1982, the Arsenal was mixing its fluid with a Venturi type mixer into a 55 gallon drum mounted on a portable cart. From past experience, it takes 15 minutes to fill the drum with mixed cutting fluid and wheel it over to a machine. MC can be calculated as follows:

MC = (15 minutes)/(60 minutes/hour) (\$31/hour, labor and overhead cost)/50 gallons = \$0.155/gallon.

%B,BC:

%B is the percent of micro-organism control concentrate that must be added to a cutting fluid in order to control the bacteria level in the machine sump. BC is the cost of the micro-organism control used. Both Trimsol and Cimcool 400 are supplied by the manufacturer with micro-organism control agents. Therefore, no additional costs will be incurred and the values for BC and %B will be zero.

%A, AC:

%A is the percent of antirust additive that has to be added to the cutting fluid sump. AC is the cost of the antirust additive. Since both cutting fluid manufacturers supply antirust additives in the cutting fluid, no additional costs will be incurred. The values for AC and %A will be zero.

The yearly fluid installation cost can now be calculated for Trimsol and Cimcool 400.

Fluid Installation Cost (Trimsol) = (12) (5,160 gallons) (0.0476) (\$7.85/gallon) + 0 + (12) (5,160 gallons) (\$0.155/gallon) + 0 + 0.

Fluid Installation Cost (Trimsol) = \$32,735.

Fluid Installation Cost (Cimcool 400) = (6) (5,160 gallons) (0.0476) (\$8.10/gallon) + 0 + (6) (5,160 gallons) (\$0.155/gallon) + 0 + 0.

Fluid Installation Cost (Cimcool 400) = \$16,736.

D.2 Maintenance Cost

Fluid Maintenance Cost = $[(NF) (\#M) (CT) (LC + EC) + (NF) (\#M) (CCC)] + (\#M) (\#S) (WPY) (MV) (\%M) (FC) + (\#M) (\#S) (WPY) (MV) (1 - \%M) (WC) + (\#M) (\#S) (WPY) (MV) (MC) + (\#M) (\#S) (WPY) (MV) (\%B) (BC) + (\#M) (\#S) (WPY) (MV) (\%A) (AC) + (APC) + (\#M) (WPY) (0.5) (CC) + (ALC).$

NF:

NF is the number of fluid changes per year. These are the same values as for the fluid installation cost: 12 for Trimsol and 6 for Cimcool 400.

#M:

#M is the number of machines that are being used. There are 172 turning machines in Shop L.

CT:

CT is the amount of time necessary to clean out a machine. The amount of time necessary to clean out a turning machine in Shop L is one hour.

LC:

LC is the labor cost per hour to clean out a machine. This cost is \$31.00/hour including overhead.

EC:

EC is the cost of having a piece of equipment idle. The cost of having a turning machine idle is not applicable at the Arsenal.

CCC:

CCC is the cleaning chemical cost per pumpout. This may be calculated by the following formula:

CCC = (sump size) (0.66) (% machine cleaning concentrate) (cost of machine cleaning concentrate).

CCC = (30 gallon sump) (0.66) (0.05) (\$6.43/gallon).

CCC = \$6.37/pumpout.

#S:

#S is the number of shifts the manufacturing facility works. The Shop L turning area works two shifts.

WPY:

WPY is the number of working days the manufacturing facility works per year. On the average, the Shop L turning area works 300 days per year.

MV:

MV is the make-up volume required per shift for a particular cutting fluid. Trimsol requires 10 gallons per shift of make-up fluid and Cimcool 400 requires 20 gallons.

%M:

%M is the percent make-up cutting fluid concentrate required for a particular cutting fluid. Trimsol requires a 4.76 make-up percentage (20:1) and Cimcool 400 requires 2.78 percent make-up (35:1).

FC:

FC is the cutting fluid cost. Trimsol's cost is \$7.85 per gallon and Cimcool 400 cost is \$8.10 per gallon.

WC:

WC is the water cost per gallon. Since deionized water is not being used, the water cost will be zero.

MC:

MC is the cost incurred when the cutting fluid is mixed by a laborer. This value is calculated the same way as in fluid installation cost and is \$0.155/gallon.

%B, BC:

%B is the percent of micro-organism control concentrate that must be added to a cutting fluid in order to control the bacteria level in the machine sump. BC is the cost of the micro-organism control agent used. As in the fluid installation cost, these values will be zero.

%A, AC:

%A is the percentage of antirust additive that must be added to a cutting fluid sump. AC is the cost of the cutting fluid additive. As in the fluid installation cost, these values are zero.

APC:

APC is the average PH control chemical cost per year. In general, small individual machine sumps do not require PH control. This is because the daily make-up volume will usually take care of any PH variations. Therefore, the PH control chemical cost per year will be zero for this comparison.

CC:

CC is the cost to check a machine sump's concentration. Assuming a refractometer is used to check a machine sump's concentration for Trimsol, it should take 4 minutes to make a concentration check. The labor rate for a concentration checker is \$31.00 per hour. Using the following formula, the value for CC may be calculated.

CC = (time for concentration check) (1 hour/60 minutes) (labor cost/hour).

CC (Trimsol) = (4 minutes/machine) (1 hour/60 minutes) (\$31.00/hour).

CC (Trimsol) = \$2.06/machine.

Cimcool 400 requires a titration in order to check its concentration. The titration should take 7 minutes.

CC (Cimcool 400) = \$3.62/machine.

ALC:

ALC is the average laboratory checking cost per year. It is assumed that 8 hours of laboratory checking procedures will be required per week. Some of the procedures required are fluid titration checks and bacteria level checks. The hourly rate paid to a laboratory worker including overhead is \$32.25/hour. The ALC may be calculated using the following formula:

ALC = (hours per week required) (52 weeks/year) (hourly rate).

ALC = (8 hours) (52 weeks/year) (\$32.25/hour).

ALC = \$13,416.

The yearly fluid maintenance cost can now be calculated for Trimsol and Cimcool 400.

MC (Trimsol) = $\left[(12) (172) (1.0 \text{ hours}) (\$31.00/\text{hour} + \$xx.xx/\text{hour}) + (12) (172) (\$6.37) \right] + (172) (2) (300) (6 \text{ gallons}) (0.0476) (\$7.85/\text{gallon}) + 0 + (172) (2) (300) (6 \text{ gallons}) (\$0.155/\text{gallon}) + 0 + 0 + 0 + (172) (300) (0.5) (\$2.06) + \$13,416.$

MC (Trimsol) = \$471,042.

MC (Cimcool 400) = $\left[(6) (172) (1.0/\text{hour}) (\$31.00/\text{hour} + \$xx.xx/\text{hour}) + (6) (172) (\$6.37) \right] + (172) (2) (300) (12 \text{ gallons}) (0.0278) (\$8.10/\text{gallon}) + 0 + (172) (2) (300) (12 \text{ gallons}) (\$0.155/\text{gallon}) + 0 + 0 + 0 + (172) (300) (0.5) (\$3.62) + \$13,416.$

MC (Cimcool 400) = \$611,817.

D.3 Disposal Cost

Disposal Cost = (NF) (#M) (AS) (DC).

NF:

NF is the number of fluid changes per year. This is the same as in the fluid installation cost. Trimsol will have 12 fluid changes per year and Cimcool 400 will have 6.

#M:

#M is the number of machines. There are 172 turning machines in Shop L.

AS:

AS is the average sump size of the equipment being used. The average sump size of the numerical control turning equipment is 30 gallons.

Note: xx.xx indicates that this item is not applicable to RIA.

DC:

DC is the disposal cost of removing the spent cutting fluid from the operating facility. Currently, the Arsenal removes its fluid by having an outside contractor haul it away at the cost of \$0.14/gallon. The yearly disposal cost can now be calculated for Trimsol and Cimcool 400.

DC (Trimsol) = (12) (172) (30 gallons) (\$0.14/gallon).

DC (Trimsol) = \$8,669.

DC (Cimcool 400) = \$4,334.

D.4 Tooling Costs

Tooling Costs = $[100\% + \%TC] [(ICY) + (RCY) + (TCI) \{ (HC) + (EC) \}]$.

%TC:

%TC is the percent increase or decrease in tooling cost. The %TC for Cimcool 400 is a -40%. Trimsol being the baseline fluid will not have a change in tool life and will have a %TC value of zero. The value of zero for %TC will give the baseline fluid 100% of the tooling cost. Using this mathematical logic, the value for the tooling cost will show how much of an increase or decrease in tooling cost exists by using a new fluid.

ICY:

ICY is the carbide tooling cost per year associated with the studied machining operation. It has been estimated that the carbide insert cost for Shop L is \$74,001 per year. We will assume that half of that value is used in turning or \$37,000.

RCY:

RCY is the yearly regrind cost. All of the turning operations use carbide inserts. For this reason, no regrinding will be necessary.

TCI:

TCI is the time required to change inserts. For the turning operations, the time required to change inserts will be conservatively estimated as 15 minutes per shift. The time to change inserts per year is 25,800 hours.

HC:

HC is the hourly cost of a machinist. The hourly cost of a machinist at the Arsenal is \$47.56/hour.

EC:

EC is the manufacturing equipment cost of being idle. The turning equipment cost of being idle is not applicable.

The yearly tooling cost can now be calculated.

$YTC \text{ (Trimsol)} = [(100\%) + (0\%)] [(37,000) + (0) + (25,800 \text{ hours}) \{ (\$47.56/\text{hour}) + (\$xx.xx/\text{hour}) \}]$.

YTC (Trimsol) = \$1,264,048.

$YTC \text{ (Cimcool 400)} = [100\% + (-40\%)] [(\$37,000) + (0) + (25,800 \text{ hours}) \{ (\$47.56/\text{hour}) + (\$xx.xx/\text{hour}) \}]$.

YTC (Cimcool 400) = \$758,429.

D.5 Miscellaneous Costs

$$\text{Miscellaneous Costs} = (\#HM) \left[(HC) + (EC) \right] + (CIC) - \left[(HC) + (EC) \right] (PRM) (CHM).$$

#HM:

#HM is the number of hours a cutting fluid manufacturer will allow production to be down before solving a cutting fluid problem. Trimsol has had a very good record at the Arsenal and will be given a #HM of zero. However, Cimcool 400 has no experience at the Arsenal. It will be estimated that the #HM for Cimcool 400 will be 16 hours.

HC:

HC is the hourly cost of a machinist. The hourly cost of a machinist at the Arsenal is \$47.56 per hour.

EC:

EC is the manufacturing equipment cost of being idle. The numerical control turning equipment cost of being idle is not applicable at the Arsenal.

CIC:

CIC is the additional cost incurred due to material incompatibility with a cutting fluid. The CIC value for Trimsol is zero. However, Cimcool 400 is not compatible with aluminum. It will be assumed that two aluminum jobs are machined each month. The cost to clean out a sump which has the Cimcool 400 in it, replace it with an aluminum compatible cutting fluid, clean out the sump again and refill it with Cimcool 400 will cost \$252. The yearly CIC cost will be \$6,408.

PRM:

PRM is the percent reduction of machining time due to the ability of a new cutting fluid to increase the feed and speed rate over the old fluid. The PRM value for this comparison will be zero because no attempts were made to increase feeds or speeds.

CMH:

CMH is the current yearly machine hours for the operation in which the new fluid will be used. The CMH value will be zero for this comparison, because no attempts were made to increase the feed or speed rates.

The yearly fluid miscellaneous costs can now be calculated.

$$MC (\text{Trimsol}) = (0) \left[(\$47.56/\text{hour}) + (\$xx.xx/\text{hour}) \right] + 0 - \left[(\$47.56/\text{hour}) + (\$xx.xx/\text{hour}) \right] (0) (0).$$

$$MC (\text{Trimsol}) = 0.$$

$$MC (\text{Cimcool 400}) = (16 \text{ hours}) \left[(\$47.56/\text{hour}) + (\$xx.xx/\text{hour}) \right] + \$6,408/\text{year} - \left[(\$47.56/\text{hour}) + (\$xx.xx/\text{hour}) \right] (0) (0).$$

$$MC (\text{Cimcool 400}) = 7,169.$$

D.6 Summation of the Elemental Costs

This section will total all of the individual cost elements which will project the yearly operating cost of one cutting fluid compared to another.

Yearly Fluid Operating Costs = fluid installation cost + maintenance cost + disposal cost + tooling cost or benefit + miscellaneous cost.

The Yearly Fluid Operating Cost (YFOC) will now be calculated for Trimsol and Cimcool 400.

$\text{YFOC (Trimsol)} = \$32,735 + \$471,042 + \$8,669 + \$1,264,048 + 0.$

$\text{YFOC (Trimsol)} = \$1,776,494.$

$\text{YFOC (Cimcool 400)} = \$16,736 + \$611,817 + \$4,334 + \$758,429 + \$7,169.$

$\text{YFOC (Cimcool 400)} = \$1,398,485.$

This comparison indicates that Cimcool 400 will generate a \$378,009 per year cost savings over using Trimsol.

APPENDIX E

APPENDIX E
A REVIEW OF PHASE II'S SEVERITY INDEX

Severity Index Considerations

Severity of a machining operation is usually considered to be a function of the level of difficulty associated with one or a combination of the parameters which describe it. For example, a turning operation's basic parameters are the speed, feed and depth of cut. In all the parameters, the higher the value the more difficult the operation. Also, each parameter must be compared to one another. In the case of turning, increasing the speed produces a more severe operation than increasing the feed; and increasing the feed produces a more severe operation than does increasing the depth of cut. These are the types of considerations taken in the development of the overall severity index.

The purpose of the severity analysis is twofold, first to establish the relative severity within a basic machining operation; secondly, to develop an overall severity index that will be used to compare all of the basic machining operations performed throughout Rock Island Arsenal. The development of the overall severity index, the index that can be related to all the basic machine operations, requires performing three separate tasks. These tasks are ranking the severity levels of the process parameters, developing a consistent scaling technique within these ranks, and extending the ranking to permit comparisons between different processes. The rationale followed for each of these tasks are described individually as follows:

1. Rank the Severity of the Critical Machining Process Variables

Each machining operation has process variables such as speed, feed, depth of cut, etc. These components are ranked on an interval scale from one to three, three being the most severe and one being the least. For example, below is how boring cutting speeds were ranked.

<u>Rank</u>	<u>SFM</u>
3	250 and above
2	100-249
1	0-99

All of the different observations of the basic machining operations being studied can then be ranked in this manner.

2. Develop a Scaling Technique to Define the Most Severe Operations of the Basic Machining Operation Being Evaluated

Establishing a quantitative ranking taking into account all the process variables whose rank was established in task one requires the development of a special technique. First, this technique involves assigning a coefficient of relative importance or weighting factors to each of the process variables rankings defined in Task 1. Second, the summation of the products of the weighting factors times their related rank then provides a

number representing the relative severity of the machine operation or observation in question. This logic is then applied to all of the observations of the basic machining operations being evaluated. The result is a representative ranking of the observations of the machining operations being studied. This ranking has been defined as the basic operation severity rank. The weighting factors must be chosen in a manner which will develop a representative spread of the severity of the operation. For example, the operation severity rank will be calculated for boring. First the ranking of each of the basic machining parameters for all the different parts observed as in Task 1 must be accomplished. This is displayed in Table E-1. Next, weighting factors must be developed to take into account the relationship between SFM, feed rate, depth of cut, hardness and metal removal rate (MRR). Past experience has shown that increasing the SFM creates a more severe operation than an increase in feedrate. An increase in feedrate produces a more difficult operation than an increase in depth of cut. Material hardness also has a major influence on machinability. Three ranges of hardness can be established to rank material machinability. Workpieces below $R_c 28$ are readily machined although the chips tend to be stringy and difficult to break. The range between $R_c 28$ and $R_c 36$ represents moderately difficult to machine steels. Alloys heat treated to hardnesses above $R_c 36$ rapidly are more difficult to machine.

All of these considerations were taken into account in the development of the weighting factors displayed in Table E-2 for the boring operation. Lastly, the summation of the products of the weighting factors with their associated rank number is calculated to form the basic operation severity rank. This operation is displayed below in detail for part number 5507239.

$$\begin{aligned}
 & (R_{\text{Speed}} = 2) (WF_{\text{Speed}} = 3) + (R_{\text{Doc}} = 2) (WF_{\text{Doc}} = 1) \\
 & + (R_{\text{Feed}} = 2) (WF_{\text{Feed}} = 2) + (R_{\text{Hardness}} = 0) (WF_{\text{Hardness}} = 100) \\
 & + (MRR = 3.8) (WF_{\text{MRR}} = 17) = 76.6 = \text{Basic Operation Severity Rank}
 \end{aligned}$$

Key: R = Rank
 WF = Weighting Factor
 Doc = Depth of Cut

These calculations are continued for all the boring operation in Table E-3.

3. Extrapolate the Basic Operation Severity Rank to an Overall Severity

The final step is to establish an index that will be used to compare the currently studied basic machining operations to all the machining operations within Rock Island Arsenal. Again, a one to three interval scale has been utilized. The highest value of the basic operation severity rank is given an overall severity index rank of three. The lowest is given an overall severity index of one. The previously discussed case of the boring was handled in a similar manner. All the values above 100 were given an overall severity ranking of three. All the values above 50 were given a two. Note, in this case, none of the values qualify for an overall severity rank of one (see Table E-5).

TABLE E-1

The Ranking of the Boring Machining Parameters

<u>SFM</u>	<u>Depth of Cut (in.)</u>	<u>Feed Rate (In/Rev)</u>	<u>Hardness</u>	<u>MRR</u>	<u>O T W</u>	<u>Operation</u>	<u>Part No.</u>
197 SFM Rank=2	0.125 Rank=2	0.013 Rank=2	NHS Rank=0	3.8	G	Bore ID	5507239
237 SFM Rank=2	0.125 Rank=2	0.015 Rank=3	R 26-32 Rank=0	5.3	-	Bore ID	8449307
294 SFM Rank=3	0.125 Rank=2	0.015 Rank=3	R 26-32 Rank=0	6.6	-	Bore ID	8449307
316 SFM Rank=3	0.060 Rank=1	0.015 Rank=3	R 26-32 Rank=0	3.4	-	Bore ID	8449307
221 SFM Rank=2	0.187 Rank=3	0.012 Rank=2	BHN 242 248 Rank=0	6.0	CH	Bore ID	6508898

Key: See Table 3.1-3

TABLE E-2
Weighting Factors for Boring

<u>Machining Parameter</u>	<u>Weighting Factor</u>
SFM	3
Depth of Cut	1
Feed Rate	2
Hardness	100
MRR	17

Turning and Boring

The turning and boring operations may be divided into two basic groups; N/C (numerical control) and conventional. N/C turning contained the most severe operations. This was due to the high surface feed at which the equipment was operated, typically, 700 to 800 SFM. Also, the N/C equipment had larger motors and heavier frames that allowed for an increased depth of cut.

In general, most of the operations observed were run above Machinability Data Handbook standards. This was due to the excellent knowledge of the area foremen and the individual machine operators of how to fully utilize carbide cutting tools and to properly apply cutting fluids. The material hardness was characteristically below the R 30 range. Most of the depths of cuts ranged from 0.100-0.250 inch. Typically, the feed rates ranged from 0.013 inch/revolution to 0.026 inch/revolution.

Each turning and boring operation was ranked for its severity in cutting speed, depth of cut, feed rate and hardness through the use of a one to three interval scale, three being the most severe and one being the least severe. Also, each turning and boring operation's metal removal rate was calculated and the mode of the observed tool wear was specified. The overall severity ranking was attributed to the combination of all these factors.

Establishment of a quantitative severity index required combining these five factors (tool wear mode was not used) in a logical manner. A weighting technique was developed which involved assigning a coefficient of relative importance to each of the five factors. Summation of the five products then provides a number representing the relative severity of the various RIA turning and boring operations. This number (the basic operation severity rank) was then converted back to a one to three interval scale which will be used to compare turning and boring to all the other machining operations. This last interval scale is called the overall severity index. The procedure is illustrated in Table E-4 for turning and Table E-5 for boring.

Drilling and Tapping

It was apparent from the analysis sheets that all drilling and tapping operations were conducted at common parameters. Most of the holes had aspect ratios in the 2-3 range with one exception. All tapping was performed at the same rates; hence, it was not necessary to develop individual indices, but a single value can be developed to describe the operations as they are currently performed.

The data observed for those operations are presented in Table E-6 for drilling and Table E-7 for tapping. A severity index was established by considering the surface speed, chip load, and aspect ratio. The index has been weighted such that a rank of two represents a high medium severity index and has been assigned a rank of two to be consistent with turning operations. However, if other holes are drilled in the future having an aspect ratio (length to diameter) greater than 3 to 1, another severity index value must be assigned. The deeper the hole the more difficult it is for cutting fluid to reach the chip/tool interface. For this type of operation, a special overall severity index classification of four is assigned.

Tapping operations involve internal thread generation in which the depth of cut is directly proportional to the hole diameter for basically all threads. The tap speed, hole depth and whether through or blind holes are produced are the critical factors for incorporating into a severity index. An overall severity index of two was established for all the tapping operations observed.

TABLE E-3

Sample Calculations for the Development of the Basic
Operation Severity Index for Boring

Part No.	Weighting Factors Times Their Related Ranks					Basic Operation Severity Rank
	(SFM)	<u>Depth of Cut</u>	<u>(Feed Rate)</u>	<u>(Hardness)</u>	<u>(MRR)</u>	
5507239	$[(R=2) \times 3] + [(R=2) \times 1] + [(R=2) \times 2] + [(R=0) \times 100] + (3.8 \times 17)$					= 76.6
8449307	$[(R=2) \times 3] + [(R=2) \times 1] + [(R=3) \times 2] + [(R=0) \times 100] + (5.3 \times 17)$					= 104.1
8449307	$[(R=3) \times 3] + [(R=2) \times 1] + [(R=3) \times 2] + [(R=0) \times 100] + (6.6 \times 17)$					= 129.2
8449307	$[(R=3) \times 3] + [(R=1) \times 1] + [(R=3) \times 2] + [(R=0) \times 100] + (3.4 \times 17)$					= 73.8
6508898	$[(R=2) \times 3] + [(R=3) \times 1] + [(R=2) \times 2] + [(R=0) \times 100] + (6.0 \times 17)$					= 115.0

From the above presentation it can be noted that the operation with the 129.2 severity rank is the most severe operation and the operation with the 73.8 severity rank the least.

TABLE E-4

Summary Table for Turning Severity Index Determination

Weighting Factors	3	1	2	100	6	Basic		Part No.
						Operation	Severity Rank	
Overall Severity Index	SFM	Depth of Cut	Feed Rate (in/rev)	Hardness	MRR	Operation	Severity Rank	Part No.
1	422 Rank=2	0.005 Rank=1	0.013 Rank=2	170- BHN 248 Rank=0	0.3	CH NC Facing	12.8	8449036
3	781 Rank=3	0.140 Rank=2	0.026 Rank=3	170- BHN 248 Rank=0	34.1	CR N/C Rough Turn OD	221.6	8449036
1	781 Rank=3	0.020 Rank=1	0.026 Rank=3	170- BHN 248 Rank=0	4.9	CR N/C Finish Turn OD	45.4	8449036
2	413 Rank=2	0.150 Rank=2	0.014 Rank=2	R 25-30 Rank=0	10.4	CH Turn OD with Ceramic	74.4	10891793
2+	413 Rank=2	0.150 Rank=2	0.014 Rank=2	R 29-36 Rank=1	10.4	CH Turn OD with Ceramic	174.4	10956584
2	375 Rank=2	0.100 Rank=2	0.015 Rank=2	R 33-35 Rank=1	6.7	- Turn OD	152.2	12007666
2	256 Rank=1	0.250 Rank=3	0.017 Rank=2	R 25-30 Rank=0	13.1	G Turn OD	88.6	12007623
1	423 Rank=2	0.060 Rank=2	0.015 Rank=2	R 26-32 Rank=0	4.6	CR Turn OD	39.6	8449307
3	848 Rank=3	0.140 Rank=2	0.026 Rank=3	R 26-32 Rank=0	37.0	- N/C Turn OD	239.0	8382446
3	761 Rank=3	0.140 Rank=2	0.026 Rank=3	R 26-32 Rank=0	32.0	- N/C Turn OD	209.0	8382446

TABLE E-4 (continued)

Weighting Factors	3	1	2	100	6	Basic Operation Severity Rank	OTW	Operation	Part No.
Overall Severity Index	SFM	Depth of Cut	Feed Rate (in/rev)	Hardness	MRR	Rank			
2	411 Rank=2	0.140 Rank=2	0.018 Rank=2	R _C 20-25 Rank=0	12.4	86.4	-	N/C Turn OD	10895646
Ranking	500-UP=R=3	0.250-UP=R=3	0.026-UP=R=3	41-46=R=2		200-UP=R=3			
Criteria	300-499=R=2	0.060-0.244=R=2	0.01-0.025=R=2	35-40=R=1		50-199=R=2			
	100-299=R=1	0-0.059=R=1	0-0.009=R=1	0-34=R=0		0-49=R=1			

Key: See Table 3.1-3

TABLE E-5

Summary Table for Boring Severity Index Determination

Weighting Factors	3	1	2	100	17	Basic Operation Severity Rank		OTW	Operation	Part No.
						Hardness	MRR			
Overall Severity Index										
2	SFM 197 Rank=2	Depth of Cut 0.125 Rank=2	Feed Rate (in/rev) 0.013 Rank=2	NHS Rank=0	3.8	76.6		G	Bore ID	5507239
3	237 Rank=2	0.125 Rank=2	0.015 Rank=3	R 26-32 Rank=0	5.3	104.1		-	Bore ID	8449307
3	294 Rank=3	0.125 Rank=2	0.015 Rank=3	R 26-32 Rank=0	6.6	129.2		-	Bore ID	8449307
2	316 Rank=3	0.060 Rank=1	0.015 Rank=3	R 26-32 Rank=0	3.4	73.8		-	Bore ID	8449307
3	221 Rank=2	0.187 Rank=3	0.012 Rank=2	BHN 242 248 Rank=0	6.0	115.0		CH	Bore ID	6508898

Ranking Criteria 250-UP=R=3 0.150-UP=R=3 0.015-UP=R=3 40-45=R=10 100-UP=R=3
 100-249=R=2 0.100-0.144=R=3 0.012-0.014=R=2 35-40=R=1 50-99=R=2
 0-99=R=1 0-0.099=R=1 0.014=R=2 0-34=R=0 0-49=R=1 0-0.013

Key: See Table 3.1-3

Milling Operations

Milling operations at RIA can be placed in three basic categories: face, end, and peripheral milling. These operations are performed on either N/C or conventional machine tools. The N/C equipment was operated at speed ranges of 400-700 SFM, somewhat higher than the 100-350 SFM range of the conventional machines. Many of the face milling operations were performed without the use of a cutting fluid.

The milling operations were organized into three categories in order to define their severity index more accurately. These categories are face milling, end milling and conventional peripheral milling. Each of these utilize different tool geometries and have different parameter ranges which are presented in Tables E-8 to E-10.

The feed per tooth and the feed rates varied depending on the operation. The hardness, except for two cases, of all the operations observed, was less than R_c 30 which machines more readily than R_c 35. The exceptions were given special considerations when their severity index was developed.

Each of the three categories of milling was separately ranked for its severity in speed, feed per tooth, feed rate and hardness through the use of a one to three interval scale, three being the most severe and one being the least severe. Also, each milling operation's metal removal rate was calculated and the mode of the observed tool wear was specified. The overall severity ranking was attributed to the combination of all of these factors.

Establishment of a quantitative severity index required combining these five factors (tool wear mode was not used) in a logical manner. A weighting technique was developed which involved assigning a coefficient of relative importance to each of the five factors. Summation of the five products then provides a number representing the relative severity of the various RIA milling operations. This number was then converted back to a one to three interval scale, three being the most severe and one the least. This procedure is illustrated in Tables E-8 through E-10.

Grinding Operations

Grinding requirements for Rock Island Arsenal are somewhat different from most commonly encountered grinding operations. Grinding is typically used to machine hard or difficult to machine parts where other types of machining processes cannot be utilized. The unique feature at Rock Island is that the bulk of the material being ground is unhardened 4100 series steels. The surfaces being ground are most commonly wear surfaces which must be ground to specific surface finishes to provide for adequate film lubrication during service, or to provide a sufficiently qualified surface for subsequent chrome plating. The chrome plating is used to provide superior wear resistance during service. Several production grinding operations were examined. These operations were done either on cylindrical or surface grinders and are presented in Table E-11.

Observations regarding grinding equipment at Rock Island Arsenal were made and may be summarized by the following:

1. Spindle speeds are governed by constant speed AC motors. Thus the actual surface speeds of the wheels decrease as the wheel radius decreases during use.

TABLE E-6

RIA Manufacturing Process Data Analysis Sheet for Drilling

<u>Part No.</u>	<u>Operation</u>	<u>SFM</u>	<u>Depth of Hole</u>	<u>Feed Rate</u>	<u>Hardness</u>	<u>L/D</u>
8447309	Spot Drill	157	0.525	0.0025	NHS	DNA
8447309	Drill	59	0.863	0.0075	NHS	1.3
8447309	Drill	59	1.5	0.0075	NHS	2.7
8447309	Drill	52	0.50	0.0067	NHS	1.1
8447309	Drill	51	0.5	0.004	NHS	2.6
8447309	Drill	55	0.63	0.0096	NHS	0.8
8447309	Drill	41	1.0	0.003	NHS	6.4
8449309	Core Drill	70	3.5	0.01	NHS	DNA

Key: SFM = Tool velocity, surface feet per minute.
 Feed Rate = Tool advancement rate in inches per revolution.
 L/D = Length of hole/diameter of hole.
 DNA = Does not apply.

TABLE E-7

RIA Manufacturing Process Data Analysis Sheet for Tapping

<u>Part No.</u>	<u>Operation</u>	<u>Hole Type</u>	<u>SFM</u>	<u>Depth of Hole</u>	<u>Feed Rate</u>	<u>Hardness</u>
8449309	1/2-20 UNF Tap	B	26.2	1.00	10	NHS
8449309	1/4-20-UNC-2B Tap	B	13.0	0.5	10	NHS
8449309	1-8 UNC-2B Tap	B	21.0	2.62	10	NHS
8449309	10-32 UNF-2B Tap	T	16.0	1.0	10	NHS

Key: SFM = Tool velocity, surface feet per minute.
 Feed Rate = Tool advancement rate, inches per minute.
 Hole Type = B = Blind Hole, T = through hole.
 NHS = No hardness specified.

TABLE E-8

Summary Table for Face Milling Severity Index Determination

Weighting Factors	3	1	2	200	2	Basic Operation Severity Rank	0	Part No.
Overall Severity Index	SFM	Feed/Tooth (in.)	Feed Rate (in/min)	Hardness	MRR	Rank	TW	
1	314 Rank=2	0.002 Rank=1	4-8 Rank=3	NHS Rank=0	60	133	CH	8449309
3	702 Rank=3	0.003 Rank=2	12.5 Rank=3	R 25-30 Rank=0	316	649	-	10884271
2	650 Rank=3	0.002 Rank=1	7.6 Rank=3	R 31-38 Rank=1	119	454	CH	7793063
2	629 Rank=3	0.002 Rank=1	8.0 Rank=3	NHS Rank=0	121	258	CH	8444309

Ranking 500-UP=R=3 0.005-UP=R=3 7-UP=R=3 42-46=R=2 500-UP=R=3
Criteria 300-499=R=2 0.003-0.0049 3-6.9=R=2 35-41=R=1 250-499=R=2
0-299=R=1 =R=2 0-2.9=R=1 0-34=R=0 0-249=R=1
0=0.0029=R=1

Key: SFM = Tool velocity, surface feet per minute.

Feed per Tooth = Amount of material each tooth removes in inches.

Feed Rate = Tool advancement rate, inches per minute.

OTW = Observed tool wear mode.

MRR = Metal removal rate, cubic inches per minute.

NHS = No hardness specified.

CH = Chipping

CR = Cratering

G = Balance between cratering and tool flank wear.

R = Rank

TABLE E-9

Summary Table for End Milling Severity Index Determination

Weighting Factors	3	1	2	4	Basic		Part No.
					Operation Severity Rank	Operation T W	
Overall Severity Index	SFM	Feed/Tooth (in.)	Feed Rate (in/min)	Hardness	MRR		
1	60 Rank=1	0.0015 Rank=1	1.5 Rank=1	NHS Rank=0	2	14	8447309 N/C End Milling
3	334 Rank=2	0.001 Rank=1	2.0 Rank=1	NHS Rank=0	40	169	8447309 N/C End Milling
2	62.4 Rank=1	0.008 Rank=3	2.0 Rank=1	NHS Rank=0	12	56	7133213 End Milling
1	32 Rank=1	0.004 Rank=2	2.0 Rank=1	NHS Rank=0	3	19	6532032 End Milling
1	63 Rank=1	0.0016 Rank=1	3.0 Rank=2	NHS Rank=0	4	24	8441309 N/C End Boring, N/C
1	57 Rank=1	0.003 Rank=2	3.0 Rank=2	NHS Rank=0	6	33	8449300 End Milling Boring, N/C
1	64 Rank=1	0.001 Rank=1	6.0 Rank=2	NHS Rank=0	5	28	8449300 End Milling Boring, N/C

Ranking Criteria 500-UP=R=3 0.005-UP=R=3 7-UP=R=3 42-46=R=2 150-UP=R=3
 300-499=R=2 0.003-0.0049 =R=2 3-6.9=R=2 35-41=R=1 50-149=R=2
 0-299=R=1 =R=2 0-2.9=R=1 0-34=R=0 0-49=R=1

Key: See Table 3.1-15

TABLE E-10

Summary Table for Conventional Peripheral Milling Severity Index Determination

Weighting Factors Overall Severity Index	3	SFM	1	Feed/Tooth (in.)	2	Feed Rate (in/min)	200	Hardness	MRR	Basic Operation Severity Rank	0	T	W	Operation	Part No.
2	3	314 Rank=2	0.005- 0.008 Rank=3	3-5 Rank=2	150 Rank=0	313	NHS	Rank=0	267	549	CH	-	-	N/C Slot Milling	8449309
3	3	398 Rank=2	0.004- 0.007 Rank=3	5-8 Rank=3	Rank=0	549	NHS	Rank=0	267	549	CH	-	-	N/C Slide Milling	8449309
1	3	314 Rank=2	0.003- 0.004 Rank=2	3-4 Rank=2	Rank=0	118	NHS	Rank=0	53	118	CH	-	-	N/C Side Milling	8449309
2	3	47 Rank=1	0.005 Rank=3	2.63 Rank=1	Rank=0	422	R _C 42-46 Rank=2	Rank=0	7	422	-	-	-	Peripheral Milling	7791379

Ranking Criteria
 500-UP=R=3 0.005-UP=R=3 7-UP=R=3 42-46=R=2 500-UP=R=3
 300-499=R=2 0.003-0.0049 3-6.9=R=2 35-41=R=1 250-499=R=2
 0-299=R=1 =R=2 0-2.9=R=1 0-34=R=0 0-249=R=1
 0-0.0029=R=1

Key: See Table 3.1-15

TABLE E-11

RIA Manufacturing Process Data Analysis Sheet for Grinding

<u>Part No.</u>	<u>Operation</u>	<u>Material</u>	<u>SFM</u>	<u>Infeed</u>	<u>Work Speed</u>	<u>Crossfeed</u>	<u>Hardness</u>
10901204	OD Cylindrical Grind	4140	4200 (new wheel)	0.001 0.0005	50	1 in/rev	BHN 213/
6538758 or 6538757	Surface Grind	4140	6021 (new wheel)	0.001 0.0005	35 35	0.200/pass 0.200/pass	NHS NHS
12007805	Surface Grind	4140	6021 (new wheel)	0.0005 0.00025	60 60	0.130/pass 0.130/pass	R _{30/35} R _{C30/35}
12012329	Cylindrical Grinder	Al-Br Stellite	6283 (new wheel)	0.001 0.0002	25 25	1.6 in/rev	NHS
7793144	OD Cylindrical Grind	Stellite	6600 (new wheel)	0.0001 0.00025	2.5	0.009 in/rev	NHS

Note: All crossfeeds are continuous and not incremental or consistent.

Key: SFM = Wheel velocity, surface feet per minute.
 Infeed = Amount the grinding wheel moves radially per pass, inches.
 Work Speed = The rate the workpiece moves past the grinding wheel, ft/min.
 Crossfeed = Amount the grinding wheel moves axially per pass, inches.
 NHS = No hardness specified.

2. Infeeds are, in general, except for stellite, 0.001 inch for roughing operations and 0.0005 inch for finishing operations. These values can be attributed to limitations imposed by the flexibility of the parts being ground. Any larger infeed values would cause excessive part deflection creating tolerance problems.
3. On cylindrical parts, the cross feeds are larger than those normally found in the Machinability Data Handbook. This would tend to load the part being ground in the axial direction, the direction in which the part is most rigid. The metal removal rates can then be increased without sacrificing tolerance.
4. For the surface grinding operations observed, the wheels were six inches in width. A large crossfeed could be used while producing a good finish with these wide wheels.
5. Specific levels of cross feed were found to be subject to considerable variation. Machine operators were free to select parameters on an individual basis to meet surface finish and size requirements.
6. Dressing was infrequently done as compared to most operations involving intricate forms or difficult-to-grind high temperature alloys. In most cases, dressing was done once every hour and was primarily required to remove wheel loading.

The major observation is that all current grinding operations may be grouped into two severity index categories. However, since the grinding speeds are an order of magnitude higher than milling and the effective tool geometries involve highly negative rake angles, special severity indices will have to be established to adequately treat the grinding process requirements. A medium value overall severity index value of two is assigned to all of the grinding operations observed except for stellite. These operations are similar to the medium duty turning operations. They were all performed on 4100 series steels and required cooling properties from the applied cutting fluid.

The grinding of the stellite barrel operation requires the assignment of a higher overall severity index value. This operation is far more severe than even grinding hardened tool steel. This is because stellite retains a high yield strength at very high temperatures. The grinding process has been reported to take place at approximately 2000 degrees F. Stellite still retains much of its yield strength at high temperatures and causes the grinding wheel to wear at a high rate especially at the corners. This results in extremely low G-ratios compared to grinding 4100 series steels. Therefore, a special overall severity index value of five is assigned to stellite grinding.

Broaching Operations

Broaching is typically a low speed cutting operation used for the generation of various two dimensional forms. Because of the low speeds involved, the most commonly experienced type of tool wear is of the built-up-edge type. A cutting fluid for these operations should have excellent lubricating properties with adequate E.P. additives.

There was only one broaching operation in production during visits to the Arsenal. This operation consisted of producing the rifling internally in 50 caliber machine gun barrels. The fluid was applied at 300 psi through a collet where the broach entered the part. Poly-Form Oil's Topaz 7/150 oil was used for the operation and seemed to perform adequately. Parts were inspected 100% for tearing in the as-cut surface. As soon as tearing was evident, the broach tool was sent to the tool room for resharpener.

All of the broaching observed was for the 50 caliber machine gun barrels, part number 7793146. The following data are typical for this operation:

SFM:	10 ft/min
Length of Cut:	2.5 ft
Rise/Tooth:	0.0005 inch
Total Depth of Cut:	0.010 inch lands 0.050 inch grooves

The broaching operation observed, like the stellite grinding operation, is an extremely severe operation which requires a special overall severity index value. The severity index value for broaching is five.

Future Uses of the Severity Index

By following the procedures described in the preceding subsections, a severity index could be calculated for any new machining operation that the Arsenal may be required to perform. This index may be used as a planning or cost estimating tool. Fill in the blank type severity index forms which are Figures E-3 through E-7. A sample form for boring is displayed in Figure E-1. For example, a new part has to be bored having the following machining parameters: Part Number: 7771777, SFM: 255 D.O.C. = .125, Feed: .015, Hardness = 32 Rc. First, the initial data are filled in on the form (see Figure 3.1-3). Second, the metal removal rate is calculated (12"/ft x 255 SFM) (.125") (.015"/rev) = 5.74.

Next, the basic operation severity rank must be calculated. In order to accomplish this each machining parameter must be ranked. The ranking value is determined by comparing the parameter value to the chart at the bottom of the parameter's column. In the case of SFM, the rank for 255 SFM would be 3 (see Figure E-2). Once the ranks are calculated, the summation of the products of the weighting factor with their associated rank number is calculated to form the basic operation severity rank. This operation is displayed below in detail for this example:

$$\begin{aligned}
 & (R_{\text{Speed}} = 3) (WF_{\text{Speed}} = 3) + (R_{\text{Doc}} = 2) (WF_{\text{Doc}} = 1) \\
 & + (R_{\text{Feed}} = 3) (WF_{\text{Feed}} = 2) + (R_{\text{Hardness}} = 0) (WF_{\text{Hardness}} = 100) \\
 & + (MRR = 5.7) (WF_{\text{MRR}} = 17) = 113.9 = \text{Basic Operation Severity Rank}
 \end{aligned}$$

Boring Severity Index Determination Table

Weighting Factors	3	1	2	100	17	Basic		Part No.
						Operation Severity Rank	W	
Overall Severity Index	SFM	Depth of Cut (in.)	Feed Rate (in/rev)	Hardness	MRR	Operation Severity Rank	W	
	Rank=	Rank=	Rank=	Rank=				
	Rank=	Rank=	Rank=	Rank=				
	Rank=	Rank=	Rank=	Rank=				
	Rank=	Rank=	Rank=	Rank=				
	Rank=	Rank=	Rank=	Rank=				

Ranking Criteria 250-UP=R=3 0.150-UP=R=3 0.015-UP 40-45=R=10 100-UP=R=3
 100-249=R=2 0.100-0.144 =R=3 0.012- 35-40=R=2
 0-99=R=1 0.0.099 =R=1 0.014 0-34=R=0 50-99=R=2
 =R=2 =R=1 0.0.013 0-49=R=1
 =R=1

Key: SFM = Workpiece velocity, surface feet per minute. MRR = Metal removal rate, cubic inches per minute.
 Depth of Cut = Tool engagement normal to feed direction, inches. NHS = No hardness specified.
 Feed Rate = Tool advancement rate, inches per revolution. CH = Chipping.
 OTW = Observed tool wear mode. CR = Cratering.
 G = Balance between cratering and tool flank wear.

Figure E-1. Sample Severity Index Determination Sheet.

Boring Severity Index Determination Table

Weighting Factors	3	1	2	100	17	Basic Operation Severity Rank	0	W	Operation	Part No.
Overall Severity Index	SFM	Depth of Cut (in.)	Feed Rate (in/rev)	Hardness	MRR					
	255	.125	.015	32 Rc						
	Rank=3	Rank=2	Rank=3	Rank=0	5.74	113.9			Bore ID	7771777

Rank= Rank= Rank= Rank=

Rank= Rank= Rank= Rank=

Rank= Rank= Rank= Rank=

Rank= Rank= Rank= Rank=

Ranking Criteria 250-UP=R=3 0.150-UP=R=3 0.015-UP 40-45=R=10 100-UP=R=3
 100-249= 0.100-0.144 =R=3 35-40=R=1 50-99=R=2
 R=2 0.012- 0-34=R=0 0-49=R=1
 0-99=R=1 0.0099 =R=2
 =R=1 0.0013
 =R=1

Key: SFM = Workpiece velocity, surface feet per minute. MRR = Metal removal rate, cubic inches per minute.
 Depth of Cut = Tool engagement normal to feed direction, inches. NHS = No hardness specified.
 Feed Rate = Tool advancement rate, inches per revolution. CH = Chipping.
 OTW = Observed tool wear mode. CR = Cratering.
 G = Balance between cratering and tool flank wear.

Figure E-2. An Example of How to Use the Severity Index Determination Table.

Boring Severity Index Determination Table

Weighting Factors	Boring Severity Index Determination Table				
	3	1	2	100	17
	SFM	Depth of Cut (in.)	Feed Rate (in/rev)	Hardness	MRR
Overall Severity Index					
	Rank=	Rank=	Rank=	Rank=0	
	Rank=	Rank=	Rank=	Rank=	
	Rank=	Rank=	Rank=	Rank=	
	Rank=	Rank=	Rank=	Rank=	
	Rank=	Rank=	Rank=	Rank=	

Ranking Criteria	250-UP=R=3	0.150-UP=R=3	0.015-UP =R=3	40-45=R=10	100-UP=R=3
	100-249=R=2	0.100-0.149 =R=2	0.012- 0.014 =R=2	35-40=R=1 0-34=R=0	50-99=R=2 0-49=R=1
	0-99=R=1	0-0.099 =R=1	0-0.011 =R=1		

key: SFM = Workpiece velocity, surface feet per minute. MRR = Metal removal rate, cubic inches per minute.
 Depth of Cut = Tool engagement normal to feed direction, inches. NHS = No hardness specified.
 Feed Rate = Tool advancement rate, inches per revolution. CH = Chipping.
 OTW = Observed tool wear mode. CR = Cratering.
 G = Balance between cratering and tool flank wear.

Figure E-4. Blank Severity Index Determination Form for Boring.

End Milling Severity Index Determination Table

Weighting Factors	3					1					2					200					4					Basic Operation Severity Rank					0					Part No.
	SFM					Feed/Tooth (in.)					Feed Rate (in/rev)					Hardness					MRR					T W										
Overall Severity Index	Rank=					Rank=					Rank=					Rank=					Rank=					Rank=					Rank=					
	Rank=					Rank=					Rank=					Rank=					Rank=					Rank=					Rank=					
	Rank=					Rank=					Rank=					Rank=					Rank=					Rank=					Rank=					
	Rank=					Rank=					Rank=					Rank=					Rank=					Rank=					Rank=					
	Rank=					Rank=					Rank=					Rank=					Rank=					Rank=					Rank=					
Ranking Criteria	500-UP=R=3					0.005-UP=R=3					7-UP=R=3					42-46=R=2					150-UP=R=3					50-149=R=2					0-49=R=1					
	300-499=R=2					0.003-0.0049					3-6.9=R=2					35-41=R=1					0-34=R=0															
	0-299=R=1					=R=2					0-2.9=R=1					0-34=R=0																				
						0-0.0029=R=1																														

Key: SFM - Tool velocity, surface feet per minute.
 Feed per Tooth = Amount of material each tooth removes in inches.
 Feed Rate = Tool advancement rate, inches per minute.
 OTW = Observed tool wear mode.
 MRR = Metal removal rate, cubic inches per minute.
 NHS = No hardness specified.
 CH = Chipping
 CR = Cratering
 G = Balance between cratering and tool flank wear.
 R = Rank.

Figure E-5. Blank Severity Index Determination Form for End Milling.

Face Milling Severity Index Determination Table

Weighting Factors	3		1		2		200		2		Basic Operation Severity Rank	OTW	Part No.
	SFM	Depth of Cut (in.)	Feed Rate (in/rev)	Hardness	MRR								
Overall Severity Index	Rank=	Rank=	Rank=	Rank=	Rank=	Rank=	Rank=	Rank=	Rank=	Rank=			
	Rank=	Rank=	Rank=	Rank=	Rank=	Rank=	Rank=	Rank=	Rank=	Rank=			
	Rank=	Rank=	Rank=	Rank=	Rank=	Rank=	Rank=	Rank=	Rank=	Rank=			
	Rank=	Rank=	Rank=	Rank=	Rank=	Rank=	Rank=	Rank=	Rank=	Rank=			
	Rank=	Rank=	Rank=	Rank=	Rank=	Rank=	Rank=	Rank=	Rank=	Rank=			
Ranking Criteria	500-UP=R=3	0.005-UP=R=3	7-UP=R=3	42-46=R=2	500-UP=R=3								
	300-499=R=2	0.003-0.0049	3-6.9=R=2	35-41=R=1	250-499=R=2								
	0-299=R=1	=R=2	0-2.9=R=1	0-34=R=0	0-249=R=1								
		0-0.0029=R=1											

Key:

- SFM = Tool velocity, surface feet per minute.
- Feed per Tooth = Amount of material each tooth removes in inches.
- Feed Rate = Tool advancement rate, inches per minute.
- OTW = Observed tool wear mode.
- MRR = Metal removal rate, cubic inches per minute.
- NHS = No hardness specified.
- CH = Chipping
- CR = Cratering
- G = Balance between cratering and tool flank wear.
- R = Rank.

Figure E-6. Blank Severity Determination Form for Face Milling.

Conventional Peripheral Milling Severity Index Determination Table

Weighting Factors	3			2			200			2			Basic Operation Severity Rank	Part No.
	Overall Severity Index	SFM	Depth of Cut (in.)	Feed Rate (in/rev)	Hardness	MRR	Rank	Rank	Rank	Rank	Rank			
		Rank=	Rank=	Rank=	Rank=	Rank=	Rank=	Rank=	Rank=	Rank=	Rank=			
		Rank=	Rank=	Rank=	Rank=	Rank=	Rank=	Rank=	Rank=	Rank=	Rank=			
		Rank=	Rank=	Rank=	Rank=	Rank=	Rank=	Rank=	Rank=	Rank=	Rank=			
		Rank=	Rank=	Rank=	Rank=	Rank=	Rank=	Rank=	Rank=	Rank=	Rank=			
		Rank=	Rank=	Rank=	Rank=	Rank=	Rank=	Rank=	Rank=	Rank=	Rank=			
Ranking Criteria	500-UP=R=3 300-499=R=2 0-299=R=1	0.005-UP=R=3 0.003-0.0049 =R=2 0-0.0029=R=1	7-UP=R=3 3-6.9=R=2 0-2.9=R=1	42-46=R=2 35-41=R=1 0-34=R=0								500-UP=R=3 250-499=R=2 0-249=R=1		

Key: SFM - Tool velocity, surface feet per minute.
 Feed per Tooth = Amount of material each tooth removes in inches.
 Feed Rate = Tool advancement rate, inches per minute.
 OTW = Observed tool wear mode.
 MRR = Metal removal rate, cubic inches per minute.
 NHS = No hardness specified.
 CH = Chipping
 CR = Cratering
 G = Balance between cratering and tool flank wear.
 R = Rank.

Figure E-7. Blank Severity Determination Form for Peripheral Milling.

Key: R = Rank
WF = Weighting Factor
Doc = Depth of Cut

The final step is to calculate the overall severity index. At the bottom of the column of the basic operation severity rank is the table of values used to determine this value. For our example, the overall severity rank should be 3. A considerable amount of discussion preceded selection of three basic severity index ranges. It was felt that a larger number of range intervals would defeat the basic purpose of this program, to simplify fluid selection procedures.

APPENDIX F

APPENDIX F

CUTTING FLUID CLARIFICATION DEVICES

This appendix will describe some of the more popular methods of cutting fluid clarification.

Belt Skimmers

A belt skimmer is a device that rotates a belt made of rubber or metal in and out of a cutting fluid sump. As the belt rotates, it picks up tramp oil that is floating on the surface of the sump. The belt skimmer is able to pick up floating tramp oil and some free floating particles. It works best when the machining equipment is not in use as during an off shift. This unit will not remove fine particulate matter or tramp oil that is dispersed throughout the cutting fluid. Also, it tends to remove good cutting fluid and its belts are easily damaged.

Centrifuge

The cutting fluid flows into a spherical open bowl that spins at a high RPM. Centrifugal force pushes the swarf to the outside of the bowl. Clean fluid spills over the top of the bowl and is held in a clean fluid reservoir. As the sludge builds up in the bowl, it must be cleaned out. This is either accomplished automatically or manually, depending on the type of unit being utilized. Centrifuges have the ability to remove floating tramp oils, dispersed tramp oils, loosely emulsified tramp oil, and particles down to 5 microns. High initial costs, high maintenance costs, and required pre-screening are the main disadvantages of a centrifuge.

Coalescers

Coalescers remove free floating and dispersed tramp oil. One method of accomplishing this is by flowing the oil through a porous media bed which causes the dispersed oil molecules to come together and float to the surface of a tank where they are skimmed off with the free floating tramp oil. Another method is heating the cutting fluid to 160 to 180°F. Again, this causes the dispersed tramp oil to join the free floating tramp oil on the surface of the tank where it is skimmed off. However, this method has a side benefit of killing the majority of bacteria in the fluid which reduces the need for biocides in some cases. Both methods do not remove emulsified tramp oil.

Gravity Filters

Gravity filters usually use material (cloth or paper) that comes in a roll through which the dirty cutting fluid flows. Some systems employ metal screens. As the contaminants build up on the filter, the filter is indexed to a fresh portion. Some advantages of this method are: relatively high flow rates, limited floor space, simple to operate, and the ability to filter to 10 microns. The disadvantages are: high initial cost, high filter media cost, high media disposal cost, overflow of solids into clean cutting fluid, high maintenance cost, and it does not remove tramp oil.

Gravity Separator

Gravity separators are used to remove floating tramp oil. As cutting fluid enters the separator, it is given time to allow the tramp oil to separate and float to the surface. When a specified volume of fluid has entered the system, the settled cutting fluid overflows

into another container which catches the tramp oil that has risen to the top of the tank. The clean cutting fluid is drawn from the bottom of the tank.

Hydrocyclone

The operation of a hydrocyclone requires that the cutting fluid initiating from the machine goes directly into a settling tank where large swarf or chips settle to the bottom. The partially cleaned fluid is pumped through the cone-shaped filter unit where it enters tangentially at the top of the hydrocyclone. As the fluid spirals downward, its velocity increases due to the shape of the cone. The conical shape of the hydrocyclone causes the radial forces of the cutting fluid to increase to about 2000 times that of gravity. This increasing force causes the swarf particles to move downward along the outside of the cone. At the apex of the cone, the cutting fluid starts to move up the center of the cone as the swarf particles are forced out the bottom through a discharge orifice. The clean cutting fluid continues to move up the center of the cone to the top where it is piped back to a clean fluid reservoir. A hydrocyclone, due to its operating principal, promotes emulsification and its small size makes it ideal for individual machine applications. However, the larger the hydrocyclone the lower its efficiency. This is why many small hydrocyclones are connected in banks when used for large applications. Low maintenance costs and no disposable media costs are the main advantages of this type of filter system. However, the hydrocyclone does not remove very small fines and large particles must be removed prior to its use or it will become clogged. Some cutting fluids experience foaming problems with a hydrocyclone. Also, tramp oil is not removed with this type of system.

Magnetic Separators

Magnetic separators remove ferrous particles from a cutting fluid by attracting them to a magnetized surface of a rotating drum. Scraper blades remove the particles from the drum while the cleaned cutting fluid is returned to the machine. Magnetic separators are usually used on individual machines or in conjunction with other filter systems. This device requires minimal maintenance and floor space.

Multiple Weir System

A sophisticated version of a settling tank is the multiple weir or folded weir system. The tank contains a series of troughs arranged in parallel to allow the cutting fluid to continuously flow over them. This system has two compartments, a clean and a dirty one. The dirty fluid flows into the dirty compartment where mechanical devices skim off floating fines and free tramp oil into a bin. Next, the fluid flows under a restraining wall to the other side and rises at a slow flow rate over the weirs into the discharge troughs. Then it flows into the clean compartment. Such a system reduces the amount of settling time in a minimum amount of space. The weirs create a surface turbulence which disrupts settling, and their parallel arrangement provides much more overflow area as does a single weir. A drag-out chain is also employed to remove settled fines. This type of system is inexpensive to operate and maintain.

Pressure Filters

Pressure filters operate similar to gravity filters except the cutting fluid is forced through the unit under pressure. A pressure filter generally contains two horizontal compartments. The top compartment is movable and the bottom is stationary. During operation air pressure seals these compartments together. The filter media is indexed

between the two halves on a nylon belt. In some installations, the belt is the filtering media. A cutting fluid deposits its particles on the filter media as it is forced through. As these particles build up, the pressure of the unit increases (typically 6 to 9 psi) which causes the filter to automatically index. This type of filter has the ability to remove small fines very efficiently and handle large volumes of fluid with a minimum floor space. However, tramp oil tends to clog this type of filter. The operating and maintenance costs tend to be high for this method of filtration.

Separators with Drag Conveyors

Separators with a drag conveyor type filter system utilize the principle of gravity settling. As the fluid flows into the low profile holding tank, the heavier (usually large) particles or swarf fall to the bottom of the tank. Scraper blades move along the bottom of the tank forcing the solids into a catch bucket. This method has a high initial cost, requires a lot of floor space, does not remove tramp oils and its operating speed can be very slow depending on its design.

Tube or Leaf Filters

Tube or leaf filters operate by vacuum or by pressure. A cutting fluid is forced into a compartment containing the filter tubes or leaves. These elements are generally composed of tubular nylon or woven wire. Particles are deposited on the outside of these tubes as the cutting fluid passes through these elements to the clean section of the system. As the particles form a cake on the outside of the tubes, the pressure rises. At a predetermined pressure the filter system initiates a backflushing operation. Compressed air or the clean fluid forces the filter cake into a conveyorized compartment where it will be disposed of later. When extremely clean cutting fluid is needed, to 0.5 of a micron, a precoat material such as diatomaceous earth is pumped through the filter which forms a secondary coating. After the precoating process, the filter operates as usual. This type of filter system offers the smallest particle size filtration available. When used with some emulsions, it has been known to remove product components. The cost for operating this system is quite high and it will plug easily.

Vacuum Filters

Vacuum filters operate similar to gravity filters except the cutting fluid is forced through the media by vacuum pressure. It is composed of a tank which holds the fluid and a filtering chamber which is covered by a filtering media. As the cutting fluid flows through the filter media, it leaves behind particles. When this cake of particles accumulates enough to increase the vacuum pressure to a predetermined point, the filter indexes a conveyor which exposes fresh filter media and the filtrate is returned to the machines. This type of system can efficiently filter up to a 10 micron particle size in almost any type of cutting fluid. Vacuum filters require large amounts of floor space and have high operating costs. Also, hard water soaps may cause plugging of the filter media.

APPENDIX G

APPENDIX G

Appendix G contains the following instructional procedures:

1. Total alkalinity procedure for concentration of Cincinnati Milacron's Cimcool 400.
2. Titration procedure to determine the concentration of the total anionic surfactant of Cincinnati Milacron's Cimcool 400.
3. Cationic titration method for determining the concentration of D.A. Stuart's Dascool 502.
4. Procedure to determine percent biocide (Dasco B2820) in D.A. Stuart's Dascool 502.
5. Procedure used to determine the concentration of suspended solids.
6. Procedure to determine the amount of concentrate and water needed to be added to a known quantity and concentration of cutting fluid in-order to bring it to a specified concentration.

TOTAL ALKALINITY TITRATION PROCEDURE FOR CONCENTRATION
OF CININNATI MILACRON'S CIMCOOL 400

- I. The following equipment and materials are required which are supplied by Cincinnati Milacron:
- a. Betz Titrating Equipment (1)
 - b. 125-ml Erlenmeyer Flask (1)
 - c. 25-ml Graduated Cylinder (1)
 - d. 20-ml Volumetric Pipette (1)
 - e. 1-ml Graduated Pipette (1)
 - f. 4-oz Square Bottle (1)
 - g. Rubber Pipetting Bulb (1)
 - h. Solution G
 - i. 0.1N Hydrochloric Acid
- II. The titration procedure is as follows:
- a. Prepare a known dilution of the cutting fluid with PLANT water. Please add fluid concentrate to water.
 - b. Using the pipetting bulb, pipette 20-ml of the known mix into the 125-ml Erlenmeyer flask. Please measure amount of mix accurately. Remove the pipetting bulb and drain the pipette, but do not expel the last drops.
 - c. Add 10 drops of Solution G. The mixture will turn blue.
 - d. Fill the burette with 0.1N hydrochloric acid, and begin titration. Gently swirl the flask with one hand while adding the acid from the burette with the other.
 - e. When the blue color disappears, stop the titration and record the volume of acid needed to reach the endpoint.
 - f. Repeat Steps b-e for the unknown mix.
 - g. Calculate the concentration of the unknown mix using the formula:

$$\frac{\text{Concentration of Known Mix}}{\text{ml of Acid for known}} \times \frac{\text{ml of Acid for unknown}}{\text{Concentration of Unknown Mix}} =$$

Example: A plant sample was titrated and found to require 19.1 ml of acid to reach the endpoint. A 1:40 (2.5%) known mix of the same product required 14.4 ml of acid to reach an endpoint. What is the concentration of the plant sample?

$$40 \times \frac{14.4}{19.1} = 30 \text{ or } 1:30 \text{ (3.3\%)}$$

TITRATION PROCEDURE TO DETERMINE THE
CONCENTRATION OF THE TOTAL ANIONIC
SURFACTANT OF CININNATI MILACRON'S
CIMCOOL 400

- I. The following equipment and materials are required which are provided by Cincinnati Milacron:
- | | |
|-----------------------------|--|
| a. 25 ml Burette | e. 4 oz. Round Oil Sample Bottle and Cap |
| b. 10 ml Graduated Pipette | f. BCG Buffer |
| c. 10 ml Volumetric Pipette | g. Solvent Mixture |
| d. 15 ml Volumetric Pipette | h. 10AAZ Titrating Solution |

II. The titration procedure is as follows:

- a. The best titer values are from 8.0-12.0 ml 10AAZ. A rule of thumb for obtaining such titers is to use sample sizes as follows:
5.0 ml of chemical solutions and preformed emulsions.
1.0 ml of soluble oils.
- b. Pipette the desired sample size into a 4-oz. oil bottle and add enough distilled water to make 10 ml total sample size.
- c. Add 10.0 ml BCG buffer and 15.0 ml solvent mixture. DO NOT PIPETTE SOLVENTS BY MOUTH AS VAPORS ARE TOXIC. Keep the solvent bottle tightly capped when not in use.
- d. Begin adding 10AAZ titrating solution from the burette 1.0 ml at a time. Cap and shake. Look for evidence of a blue tint in the bottom solvent layer. When this happens, begin adding 10AAZ in 0.2 ml increments, agitating between additions. The endpoint will be when both layers have the same intensity of blue. Compare against a white background to the solvent layer of the "blank". Record the volume of 10AAZ added. (If you know what the approximate titer will be, you may add 80% of the 10AAZ at once and then continue as in Step 4 without affecting the accuracy of the test.)

- e. The final step is to calculate the concentration. Be sure you used the same sample size for both the KNOWN and UNKNOWN.

$$\text{CONCENTRATION OF UNKNOWN} = \frac{(\text{Conc. of KNOWN}^1) \times (\text{ml of 10AAZ for KNOWN}^2)}{(\text{ml of 10AAZ for UNKNOWN} - \text{ml of 10AAZ for BLANK}^3)}$$

1. This is the concentration number of the known concentration sample. This number would be 20 if a 20:1 ratio was desired.
2. The known is the titration value of a known concentration of the fluid being titrated against.
3. A "blank" is simply a titration which was run without any mix sample, using instead 18 ml of distilled water, 2 ml of isopropanol, buffer and solvent as before. This titration should require from 1.2-1.4 ml 10AAZ which must be subtracted from all other titration values before calculating concentrations.

CATIONIC TITRATION METHOD FOR DETERMINING THE CONCENTRATION OF
D.A. STUART'S DASCOOL 502

I. The following equipment and materials are required:

- a. Mixing cylinder - 100 ml. size.
- b. Pipette - 10 ml.
- c. Burette
- d. Chlorothene NU solvent. (Dow inhibited 1,1,1 trichloroethane).
- e. Indicator solution prepared by mixing the following ingredients to make one liter of solution:

500 ml.	2.65%	Sodium carbonate solution
200 ml.	5.00%	Ammonium chloride solution
200 ml.	0.04%	Bromphenol blue solution
100 ml.	0.50%	Fluorescein solution

NOTE: 0.04% bromphenol blue indicator is made by neutralizing 0.08 grams bromphenol blue powder with 2 ml of 0.06 N sodium hydroxide. When dissolved, dilute to 200 ml. with distilled water.

Cationic Solution - 1% Rohm and Haas Hyamine 2339 in distilled water. The Hyamine solution is prepared by weighing 10.00 grams Hyamine 2339 and diluting the one liter with distilled water.

II. The titration procedure is as follows:

- a. Pipette 5.0 cc of emulsion into mixing cylinder.
- b. Add 15cc water.
- c. Add 15cc of indicator solution into emulsion.
- d. Add 20cc of chlorothene solvent (Do not pipette).
- e. Mix moderately well and allow to settle.
- f. Titrate with 0.5 ml. portions of cationic solution, mixing moderately well after each addition and allowing time between additions for separation to form so the color of solvent layer may be observed.
- g. End Point: A point is reached where the chlorothene layers turns a faint blue. Further addition of the cationic solution causes the solvent layer to turn a bright blue and the water layer simultaneously changes from milky to bright green. Either point, light blue or bright blue and green, can be taken as the end point subject to the preference of the titrator.
- h. The results obtained are compared to samples of known concentrations titrated to the same end point. For example, if a 5% known solution require 4.0 ml. of titrant, and an unknown solution titrates at 6.0 ml., the concentration may be determined by the following calculation.

$$\begin{aligned}\frac{\%}{4.0 \text{ ml.}} &= \frac{5\% \times 6.0 \text{ ml.}}{4.0 \text{ ml.}} \\ \% &= 7.5\end{aligned}$$

PROCEDURE TO DETERMINE PERCENT BIOCIDES (DASCO B2820)
IN D.A. STUART'S DASCOOL 502

Reagent - Nash's Reagent

Dissolve 75 grams of ammonium acetate in 150 to 200 mls. of distilled water, add 1.5 mls. of glacial acetic acid and 1.0 ml. of acetyl acetone (2,4 pentanedione). Transpose quantitatively into a 500 ml. beaker using distilled water as solvent and add sufficient distilled water to the 500 ml. mark. Mix well.

Preparation of Standard Curve

Prepare a solution containing 0.1% of Dasco B2820 W/V in a cutting oil emulsion. Place 10 mls. of the prepared solution into a steam distilling flask, add 20 mls. of 10% sulfuric acid to the flask and submit to steam distillation. Condense the distillate and collect 100 mls. of distillate in a 100 ml. volumetric flask. Mix the distillate well.

Place an aliquot of 0.5 and 1.0 ml. of the distillate (strain through a plug of cotton if cloudy) into each of two test tubes. Add 1.5 ml. of distilled water to the first tube and 1.0 mls. of water to the second tube. Prepare a blank by adding 2 mls. of distilled water to a third tube. To each tube add 2 mls. of Nash's reagent. Mix well by shaking and place the tubes in a water bath at 37°C (+ 1°C) for exactly 30 minutes. Read the absorbance on a spectrophotometer or a suitable colorimeter at 415 mu.

Plot the absorbance as the vertical and the weight of the Dasco B2820 in milligrams as the horizontal.

Analysis of Sample

Place 10 mls. of the cutting oil emulsion in a steam distilling flask. Add 20 mls. of 10% sulfuric acid and submit contents to steam distillation. Collect 100 mls. of distillate in a 100 ml. volumetric flask. Mix the distillate well.

Transpose 1 ml. (pipette) into a test tube, add 1 ml. of distilled water and 2 mls. of Nash's reagent. Prepare a blank using 2 mls. of distilled water and 2 mls. of Nash's reagent. Place the tubes in a water bath and maintain at 37°C. (+ 1°C) for 30 minutes.

Read the absorbance of the sample against that of the blank at 415 mu. From the absorbance determine the weight of Dasco B2820 in milligrams from the prepared standard curve.

Convert the weight from milligrams to grams and calculate the percentage of Dasco B2820 in the original sample as follows:

$$\frac{\text{Weight of Dasco B2820 in grams} \times 100}{0.1 \text{ (Ml. Sample)}} = \text{Percent Dasco B2820}$$

PROCEDURE USED TO DETERMINE THE CONCENTRATION OF SUSPENDED SOLIDS

I. The following equipment is required:

- a. Millipore funnel
- b. Vacuum flask
- c. Vacuum pump
- d. Millipore membrane papers*
- e. Forceps
- f. Squeeze bottle
- g. Drying oven
- h. Analytical balance

II. The preweighing of the membrane papers requires the following:

- a. Dry the Millipore papers in oven for 20 min. at 90° C.
- b. Cool papers in dessicator for 20 minutes.
- c. Weigh and record marked papers with analytical balance.

These papers should be handled with forceps at all times.

III. The filtering procedure involves:

- a. Set up vacuum operation and place preweighed paper on funnel.
- b. Pour aliquot of sample through membrane paper.
- c. Rinse graduate, funnel and paper with washwater.
- d. Redry papers in oven for approximately 20 minutes at 90° C, then cool for 20 minutes in dessicator. Reweigh papers.

IV. After cooling, the concentration of suspended solids is determined by:

- a. Subtract "before" weight from "after" weight.
- b. Divide the difference by the volume passed through the membrane paper to give mg./l reading.

* Other suitable material may be substituted such as Gelman glass fiber membranes or Tetko's Nitex nylon media.

PROCEDURE TO DETERMINE THE AMOUNT OF CONCENTRATE AND WATER NEEDED TO BE ADDED TO A
KNOWN QUANTITY AND CONCENTRATION OF CUTTING FLUID IN ORDER TO BRING IT TO A SPECIFIED
CONCENTRATION

Given - X gallons of Y% fluid currently exists

We want - Z gallons of W% solution

We must add a mixture of -

(1) $(WZ - XY)$ gallons of concentrate

(2) $Z(1-W) - X(1-Y)$ gallons of water

To the existing solution.

NOTE - Add concentrate to total volume of water first.

Or in other terms

Add $Z-X$ gallons of $\frac{WZ-XY}{Z-X}$ % solution.

For example, suppose we have 250 gallons of a 3.2% (30:1) cutting fluid solution and we want 500 gallons of a 5% (19:1) solution.

(1) Add $(.05 \times 500 - 250 \times .032) = 25 - 8 = 17$ gallons of concentrate

(2) Add $500(1-.05) - 250(1-.032)$

$= 500(.95) - 250(.968)$

$= 475 - 242 = 233$ gallons of water

In other terms

Add $500-250$ gallons of $\frac{.05(500) - 250(.032)}{500-250}$ % cutting fluid solution

Add 250 gallons of a 6.8% cutting fluid solution.

APPENDIX H

APPENDIX H

BATCH RECYCLING COMPARED TO CENTRAL SYSTEM RECYCLING FOR SHOP M'S CRANE WAY AREA (61 MACHINES)

This appendix will demonstrate the steps required to compare batch recycling to a central recycling system.

H.1 Manpower

Batch Recycling -

The following assumptions are made:

- a) Twenty-two working days per month, one shift for machine cleaning.
- b) Three hundred working days, three shifts per day for the manufacturing equipment.
- c) Sump cleaning of 1.5 hours per machine.
- d) The batch equipment can run unattended.
- e) One hour of clean-up time is required for the batch equipment per day.
- f) Machines have fifty gallon sumps and a one month sump life.
- g) Labor cost of machine cleaner is \$31.00/hour.
- h) The batch equipment will recycle one hundred gallons of fluid per hour.
- i) Ten minutes per machine is required to add daily makeup per shift.

From the above, it can be calculated that three machines per day must be cleaned at a cost of \$36,828 per year. The batch equipment cleaning cost, assuming one hour per day cleaning cost, will be \$8,184 per year. The labor cost for make-up fluid is \$283,650. Labor cost of \$328,662 per year is required for batch recycling.

Central Recycling System -

The labor cost for operating a central system for three hundred days per year, three shifts is as follows.

A chemist is required to make tests for three hours per day at \$32.25 per hour or \$29,025 per year. To insure that the system is working properly, a laborer will check it for one hour per shift at \$31.00 per hour or \$27,900 per year. The total labor cost of operating a central recycling system is \$56,925 per year.

H.2 Floor Space

Due to the fact that a value for floor space has not been developed and RIA is not lacking for space, this calculation will be left out of this evaluation. However, it should be noted that a batch system requires 19 ft x 6 ft 8 in. area, where a central system requires 82 x 24.5 ft area plus troughing area.

H.3 Electric Power

Batch recycling requires three horsepower for four hours during 264 days per year or 3,168 kwh per year. The Arsenal's electric cost is \$0.04 per kwh or \$127 per year electric cost. Also, batch recycling requires the power of the individual machine sumps which is 395,568 kwh per year. This will cost \$15,823 per year. The total batch power cost is \$15,950. A central system requires 600 horsepower for three shifts during 300 days per year or 3,221,424 kwh; this results in a yearly power cost of \$128,857 per year.

H.4 Yearly Maintenance Cost

The yearly maintenance cost for batch recycling is \$3,300 per year. This was based on a maintenance contract cost and having to change centrifuge bearings every three years. The estimated central recycling maintenance cost is \$5000 per year. This cost was based on the costs of various parts that are known to go bad in a central system and the cost of repairing them. Also, included in the yearly cost is an accrual amount that will be used for future major repairs.

H.5 Cutting Fluid Cost

The following cutting fluid costs will be incurred:

a) Initial Change Cost

The initial change for the 61 machines with 50 gallon sumps is 3,050 gallons. Forty-one cents per gallon is the mixed cutting fluid cost. Therefore, \$1,251 per year is the cost of the initial charge for the batch method.

A central system's initial charge will be 62,746 gallons and will cost \$25,728.

b) Make-up Fluid Cost

Assuming that 61 machines require 20 gallons of makeup per shift for three shifts during 300 days per year, batch recycling will require 1,098,000 gallons of makeup per year. The make-up fluid cost will be \$0.20 per gallon. The cost for batch recycling will be \$219,600 per year.

The yearly makeup required by a central system is 4,320,000 gallons per year. The make-up cost per gallon for the central system will be \$0.135 per gallon. The yearly make-up cost will be \$583,200 per year.

H.6 Disposable Filter Media Cost

The batch recycling method used requires disposable filter bags to be used in the sump cleaners. The filter bags cost \$3.60 and they will be changed once a day. The estimated cost for disposable filter media for batch recycling is \$1,080 per year.

The central system will require disposable filter media which is estimated to cost \$1,000 per year.

H.7 Ability to Relocate System

The batch recycling equipment can easily be relocated because it is mounted on skids. The only relocation cost involves new electrical and water hookups. When a central filter system has to be moved, only the filter unit can be saved, and the cost of moving it is much more than a batch recycling unit.

H.8 Plugging of the Fluid Nozzles

The sump equipment used on RIA machines has filters that eliminate cutting fluid nozzle plugging. For this example, no cost savings due to plugging can be attributed to the utilization of a central system.

H.9 Tool Life

It was conservatively estimated that a central system will increase tool life over a batch recycling method by 5% due to the reduction of metallic fines and tramp oil. This will be a \$5,500 per year cost savings.

H.10 Number of Fluids that Can Be Used

The batch recycling method may handle many fluids at different dilution ratios. Two fluids were recommended for use at RIA: one for turning/grinding and another for milling. The central recycling system can only be used with one fluid. This fact should be strongly considered, because either the milling or turning area will suffer a reduction in tool life when only one fluid can be used.

H.11 Handling Repairs

Repairs to a central recycling system must be made on the off shifts or weekends. Most central systems are designed with back-up equipment since, if the central system goes down, no fluid will be available to the machines. A batch recycling system may be repaired any time.

H.12 Concentration Control

The concentration control of a central recycling system is far more accurate and consistent than batch recycling. A central system's concentration is controlled at one point whereas the batch method has many individual machine sumps to be maintained. Also, most central systems have a chemist performing a titration to determine the system's concentration which is a more accurate method of cutting fluid concentration measurement than a refractometer. Usually, a refractometer is used by a laborer to determine the concentration of individual machine sumps found in batch recycling. The accumulation of tramp oil tends to make a refractometer read high and/or difficult to read. Many titration procedures are too difficult to be performed by a laborer. A central system can only have one cutting fluid concentration where batch recycling may have many different ones. The concentration checking costs for batch recycling is $(\$3.62/\text{titration} \times 300/2 \text{ day} \times 61 \text{ machines})$ \$33,123 per year. The concentration control cost per year for a central system is \$1,086 $(\$3.62/\text{day} \times 300 \text{ days})$.

H.13 Bacteria Control

A central recycling system makes bacteria control easier for the following reasons:

- a) There is only one location to make additions of micro-organism control additives.
- b) The cutting fluid is in constant motion which provides aeration. This reduces the anaerobic bacteria level.
- c) Individual machine sumps tend to grow bacteria at a faster rate because they are seldom cleaned out thoroughly.

It is impossible to estimate this cost without records of previous bacterial levels and additive costs.

H.14 Tramp Oil Controls

A central system has a lower level of tramp oil than a batch system because its tramp oil is constantly being removed. An individual machine sump will accumulate tramp oil until its scheduled recycling. The more tramp oil that is accumulated by a cutting fluid, the lower the performance. However, to keep this cost comparison conservative, no tooling cost savings will be attributed to the central system.

H.15 Fines Removals

A central system has a lower level of fines than batch recycling for the same reasons it has a lower level of tramp oil. This cost estimate was made under tool life.

H.16 Machine Locations

A central recycling system must have its machines located as close to the system as possible. However, batch recycling has no limitations for machine locations.

H.17 Chip Handling Savings

The most important cost to consider when comparing a central recycling system to batch recycling is that incurred for removing chips. For example, at RIA it has been estimated that 0.5 hours are required per shift to dispose of chips. A batch recycling method will still require this chip handling; however, a central recycling system will eliminate this need. The cost savings for 61 machines operating three shifts for 300 days per year is \$1,305,522 based on one-half hour per shift downtime.

H.18 Cutting Fluid Cost Savings

One of the major justifications for installing a cutting fluid recycling system is the reduction in fluid and waste disposal costs that are generated per year. For the crane way area, 61 machines having a sump capacity of 50 gallons each will require their sumps cleaned out once a month. The cutting fluid concentration is at 19:1 (5%). The mixed cost for the cutting fluid is \$0.41 per gallon and the waste disposal cost is \$0.14 per gallon. A cost savings of \$20,130 per year will be generated.

H.19 Cost and Savings Analysis

The total operating cost incurred for batch recycling when compared to a central system is \$602,839 per year with a \$20,130 per year savings. A \$582,709 cost per year is the batch systems net result. The central system has an annual cost of \$637,938 with a yearly cost savings of \$1,325,652. This central system produces a yearly saving of \$687,714, paying back its initial investment in three years. The central system is clearly the choice in this case.

Please note a batch recycling system by itself should not be justified using this method. This method was developed to compare the total operating costs of batch recycling to a central recycling system.

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The study showed the majority of observed machining operations involved milling, turning, grinding and boring procedures on 4100 series steels. Through the use of an economic model, it was demonstrated that two generic type cutting fluids can satisfy 90% of all the machining opera- tions at RIA. Also, three central cutting fluid recycling systems were recommended for use in three major production areas.		

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During the demonstration portion of the program, it was proven that laboratory tests can, indeed, be used to predict what will happen in a production environment. A 50% reduction in tooling costs was predicted through laboratory testing and verified by production tests at RIA.

Technology transfer was accomplished by: 1) a step-by-step procedure that RIA can use to evaluate future cutting fluids, 2) a specially designed procedure which RIA personnel can use to select cutting fluids within RIA, and 3) detailed quarterly and final reports.

The projected annual cost savings of this program amount to \$1,975,000.

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